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# USAAVLABS TECHNICAL REPORT 69-18

# MEASUREMENT OF ROTOR NOISE LEVELS AND EVALUATION OF POROUS BLADE TIPS ON A CH-47A HELICOPTER

By

R. H. Spencer

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September 1969

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-330(T)
THE BOEING COMPANY
VERTOL DIVISION
PHILADELPHIA, PENNSYLVANIA

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This contract was initiated to correlate CH-47A noise levels with selected CH-47A parameters and to evaluate over a broad flight spectrum the effect of "porous" blade tips on noise, performance, and fuselage vibration in comparison with the standard rotor blade tips.

It was observed that in the region of rotor overlap, the amount of vertical separation between the forward and aft rotors had a profound influence on rotor noise levels and the occurrence of blade "slap." By comparison, other parameters appeared as second-order influences.

Porous tips only modestly reduced the noise level at hover, had no significant influence on noise levels in forward flight, and failed to demonstrate an appreciable effect on blade slap. It had been estimated that the increased drag of the porous tip represented a power penalty of 120 horsepower in hover, but measured results show this penalty to be 600 horsepower in hover and to diminish with forward speed, reaching zero at 130 knots. Graphic comparison of the power required for porous and standard tips suggests that at forward speeds in excess of 130 knots, the porous tip configuration might be operated at reduced power. Scrutiny of the noise data, however, indicates that noise reductions are not achieved by this reduction in required power.

Task 1F162203A14801
Contract DA 44-177-AMC-330(T)
USAAVLABS Technical Report 69-18
September 1969

# MEASUREMENT OF ROTOR NOISE LEVELS AND EVALUATION OF POROUS BLADE TIPS ON A CH-47A HELICOPTER

Final Report

D8-0439B

By

R. H. Spencer
and
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Prepared by

THE BOEING COMPANY
VERTOL DIVISION
Philadelphia, Pennsylvania

for

U.S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

## SUMMARY

This report presents the results of a program to investigate rotor noise levels of the tandem-rotor CH-47A helicopter. The program was conducted in two phases:

### Phase I

This phase correlated acoustical data with data obtained under the Dynamic Airloads Program [Contract DA 44-177-AMC-124(T)]. The most significant correlation indicated that relative blade tip path plane positions played a larger role in setting rotor noise levels than did other operating parameters such as rotor speed or gross weight.

### Phase II

A set of porous rotor blade tips was evaluated as a means of achieving noise reduction. These tips effected a 15-db reduction in hover noise but had no consistent effect on sound pressure level in forward flight. It was noted, however, that a qualitative change in the acoustical signature resulted in decreasing the sharpness of the generated sound at all airspeeds.

## FOREWORD

The two-phase rotor noise investigation was performed by the Acoustics Unit of the Vertol Division of The Boeing Company under U.S. Army Aviation Materiel Laboratories (USAAVLABS) Contract DA 44-177-AMC-330(T), Task 1F162203A14801.

This program was conducted under the technical cognizance of Mr. J. McGarvey, Aeromechanics Division, USAAVLABS. The work was performed during the period June 1965 to February 1967, and the flight test program occurred during April and May 1966. Much of the analyses of data and calculations was performed by Miss M. Cupp and Mrs. F. Walton, and the laboratory work was performed by Messrs. K. Ritchey and R. Urban, all of Vertol.

Acknowledgment is also made of the editorial assistance of Messrs. J. Horner and L. Goldberg in the publication of this document.

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## LIST OF SYMBOLS

| | |
|---|---|
| A | attenuation, decibels |
| $A_\epsilon$ | excess attenuation due to atmospheric absorption, decibels |
| A/S | airspeed, knots |
| $a_1$ | longitudinal blade flapping coefficient |
| $a_o$ | blade coning angle, degrees |
| BITF | forward rotor longitudinal cyclic trim angle, degrees |
| BITR | aft (rear) rotor longitudinal cyclic trim angle, degrees |
| b | number of rotor blades |
| $b_1$ | lateral blade flapping coefficient |
| C | speed of sound, feet per second |
| $C_{D_o}$ | profile drag coefficient |
| CF | centrifugal force, pounds |
| C-network | acoustical weighting filter |
| $C_x$ | coordinate of vortex filament, feet |
| $C_y$ | coordinate of vortex filament, feet |
| $C_z$ | coordinate of vortex filament, feet |
| c | blade chord, feet |
| $c_r$ | equivalent circumference of blade at radius r, feet |
| db | decibels, re 0.0002 dyne/cm$^2$ |
| f | frequency, cycles per second |
| GW | gross weight, pounds |
| H | tip path plane separation, feet |
| Hz | Hertz, cycles per second |

| | |
|---|---|
| h | height of blade tip above fuselage reference line, feet |
| hp | horsepower |
| IAS | indicated airspeed, knots |
| $i_s$ | rotor shaft angle, degrees |
| kHz | kiloHertz, cycles per second x $10^{-3}$ |
| kn | knots |
| L | port length - porous tip, feet |
| l | pylon height above fuselage reference plane, feet |
| lb | force, pounds |
| M | Mach number |
| N | North |
| p | pressure, pounds per square foot |
| R | rotor blade radius, feet |
| r | distance from the center of rotation to a particular blade station, feet |
| r | vortex radius, feet |
| r, $r_o$ | distance from noise source to microphone, feet |
| rpm | rotor revolutions per minute |
| S | South |
| SPL | sound pressure level, decibels |
| T | rotor thrust, pounds |
| TAS | true airspeed, knots |
| t | time, seconds |
| t/c | blade thickness ratio |
| $V_{fs}$ | freestream velocity, feet per second |

| | |
|---|---|
| $v_i$ | induced velocity of the vortex core, feet per second |
| $v_{tot}$ | blade section total velocity, feet per second |
| $\alpha$ | angle of attack, degrees |
| $\alpha_f$ | fuselage angle with respect to the free stream, degrees |
| $\beta$ | blade flapping angle, degrees |
| $\Delta$ | incremental notation |
| $\lambda$ | wavelength, feet |
| $\mu$ | advance ratio |
| $\rho$ | density of air, $lb\text{-}sec^2/ft^4$ |
| $\tau$ | blade passage period, seconds |
| $\psi$ | blade azimuth position, degrees |
| $\Omega$ | rotor speed, radians per second |

## INTRODUCTION

The evolution of rotary-winged aircraft toward higher speeds and higher payloads has produced helicopter rotor systems with greatly increased aerodynamic loading. This loading often results in the predominance of rotor blade noise in the overall noise signature of the aircraft; the level of noise from this source can be relatively strong.

The higher airloading imposed upon the blades gives rise to stronger circulation over the blade, and, therefore, to stronger tip vortex filaments. It is generally accepted that the impulsive acoustic radiation is caused either by large angle-of-attack changes over local sections of the blade or by the effects of local shock fronts on the blade, both of which appear to result from the intersection of the blade with the rolled-up vortex filament. On a single-rotor helicopter, these intersections arise from one blade intercepting the vortex trailed from a previous blade. On a tandem-rotor helicopter, the impulse generally results from a blade on one rotor intersecting a vortex trailed by a blade on the other. For both cases, however, the phenomenon results in similar acoustic effects, regardless of the mechanism of generation; i.e., increased detection signature and annoyance.

Some work has recently been done in the area of lifting-rotor/propeller noise theory by Loewy and Sutton[1] and Schlegel et al[2]; however, a comprehensive experimental program to evaluate the effect of systematic variations in vehicle-operating variables on the external noise of the vehicle has been required in order to examine the relationship of these oscillating pressures with other effects which may be directly or indirectly associated with the mechanism of generation. This report describes such a program, conducted by Vertol Division of Boeing under contract from USAAVLABS.

Since Boeing had already contracted with USAAVLABS to perform an extensive flight test program [Investigation of Dynamic Airloads - Contract DA 44-177-AMC-124(T)], it was arranged to conduct the study described in this report simultaneously with the former program. The Dynamic Airloads Program, which measured the steady and dynamic airloads, blade dynamics, control loads, and airframe response on a CH-47A helicopter, is fully reported in Reference 3. Flight test conditions included three nominal gross weights (25,500, 32,500, and 36,000 pounds), rotor speeds from 202 to 241 rpm, and airspeeds from 0 to 148 knots, to give systematic variations in advance ratio, advancing tip Mach number, and thrust coefficient. Manual adjustment of longitudinal cyclic trim allowed independent control of rotor separation, which exerts a high degree of influence on rotor noise, particularly at high airspeeds. Approximately 250 channels of data were recorded on each flight.

By adding four channels of on-board noise-measuring equipment, it was possible to measure rotor noise simultaneously with a large number of other operating variables and to correlate those variables which exerted the highest influence on rotor noise. This effort constituted Phase I of the rotor noise measurement program covered in this report.

It had been theorized earlier that an expanded tip vortex core would result in reduced aerodynamic response of the blade when an intersection occurred. During a wind tunnel program[4] conducted on a section of model blade which simulated flow over the tip region of the rotor, ten blade tip configurations were evaluated to determine the maximum component of tangential velocity induced in the core of the vortex trailed by each configuration. It was shown in this work that a 20-percent porous blade tip was successful in expanding the diameter of the core region, while reducing the maximum velocity to approximately one-fifth that of the standard configuration.

Phase II of the noise measurement program consisted of a separate investigation of the noise-reduction potential of the porous blade tip developed in the course of the Reference 4 program. This investigation was accomplished by installing rotor blades equipped with porous tips on the aircraft previously used for the Dynamic Airloads Program and by conducting an additional flight program.

In general, this program did not meet many of its initial objectives with regard to correlating noise and operating parameters such as gross weight, tip speed, etc. This was primarily due to the fact that the effect of rotor separation proved to be much more powerful than was initially suspected, and the Dynamic Airloads Program from which the data for this program were obtained did not provide the type of flight schedule which would have made it possible to isolate this effect.

Identified and calibrated 1/4-inch magnetic tapes of all noise data recorded under this contract will be on loan from the U.S. Army Aviation Materiel Laboratories to investigators studying helicopter noise.

## ANALYSIS OF THE PROBLEM

It is generally accepted that the intersection of a rotor blade with the rolled-up (or partially rolled-up) portion of the shed vorticity results in impulsive aerodynamic loading of the rotor blade. This rapid fluctuation in aerodynamic loading gives rise to high intensity noise and suggests at least two mechanisms for the generation of this noise:

1. Rapid changes in blade angle of attack with the accompanying pressure fluctuations.

2. Local flow over a section of the blade approaching the velocity of sound, resulting in a more rapid disturbance.

Either mechanism may occur depending upon the velocity of the blade section. For example, when the blade intercepts a vortex with the total effective velocity over the blade section well below the critical Mach number for that airfoil, the mechanism of noise generation is a rapid change in the angle of attack. However, if the section is operating at high subsonic velocities, the flow over the section of the blade which passes through the vortex can approach the velocity of sound and a new mechanism is introduced. In either case, a reduction in the velocity induced within the core of the vortex reduces the intensity of the accustical disturbance produced. When the Mach number of the advancing tip of a rotor blade exceeds the critical Mach number (neglecting for the moment other disturbing flow fields), transonic or supersonic flow can exist and the conditions for local shock fronts will then prevail. The magnitude and extent of the disturbance which exists are not well understood, but the pressure disturbance on the ground has been extensively measured.

Two approaches to a solution are: to avoid intersections of rotor blades with rolled-up tip vortices, or, if this cannot be accomplished, to reduce excitation of a rotor blade with the vortex by lowering the velocity induced within the core.

It was the purpose of Phase I of this study to determine the extent to which changes in operating variables effect changes in rotor noise levels, and then to correlate the more important variables with this noise. Phase II was an investigation to determine, on a full-scale vehicle, the extent of rotor noise reduction achievable by practical reductions in the velocity induced in the tip vortex.

## MEASUREMENT OF NOISE LEVELS

### TEST AIRCRAFT

The flight vehicle used for the subject program (Figure 1) is a tandem rotor U.S. Army CH-47A Chinook helicopter (S/N 94986). The Chinook has a crew of three and is a medium transport helicopter capable of transporting 44 passengers at a maximum speed of 150 miles per hour over a range of 234 miles. It is powered by two T55-L-7 turboshaft engines and has a normal gross weight of 33,000 pounds and a rotor diameter of 59.1 feet. The general arrangement of the CH-47A is shown in Figure 2.

The control system incorporates longitudinal cyclic trim on both rotors. This permits the pilot to control the rotor tilt independently, thus controlling the tip-plane separation between the rotors.

#### Development of the Porous Tip

A wind tunnel program[4] to evaluate ten rotor blade tip configurations for the effect on tip vortex core thickening led to the development of the 20-percent nominal porous tip for the subject program (Figure 3). In general, the three porous tips, developed during the Reference 4 program, showed the most promise for reducing the velocity induced within the core of a tip vortex filament. Although the 40-percent nominal porosity blade tip provided a greater reduction in velocity, the increment in profile drag coefficient involved with this was substantial, and the 20-percent tip was judged to be the optimum.

Although original planning called for the porous blade tips to be evaluated on the instrumented blades of the Dynamic Airloads Program, chordwise balance of these instrumented blades was such that the additional mass required to balance the tips to the blades could not be retained by the existing tip-attachment hardware.

Since new fittings for the tip-attachment hardware could not be installed in the space available, the porous tips were evaluated on standard CH-47A noninstrumented rotor blades which required modification to accept the porous tips; this added an additional 4.5 pounds to the blade. The modifications consisted of three internal stiffening ribs at the tip and an external triangular doubler between the blade and tip at the midchord location.


Figure 1. CH-47A Test Aircraft.

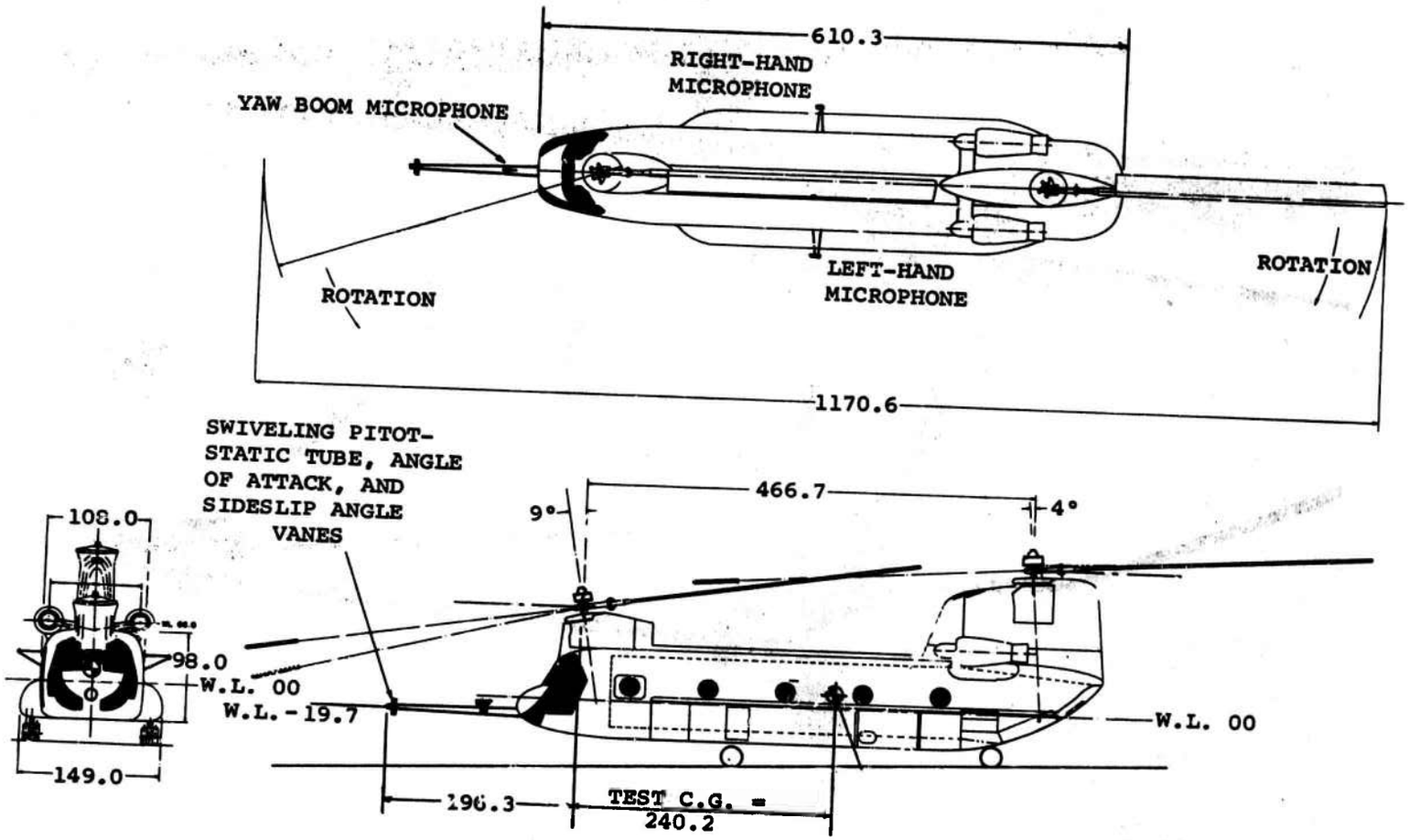
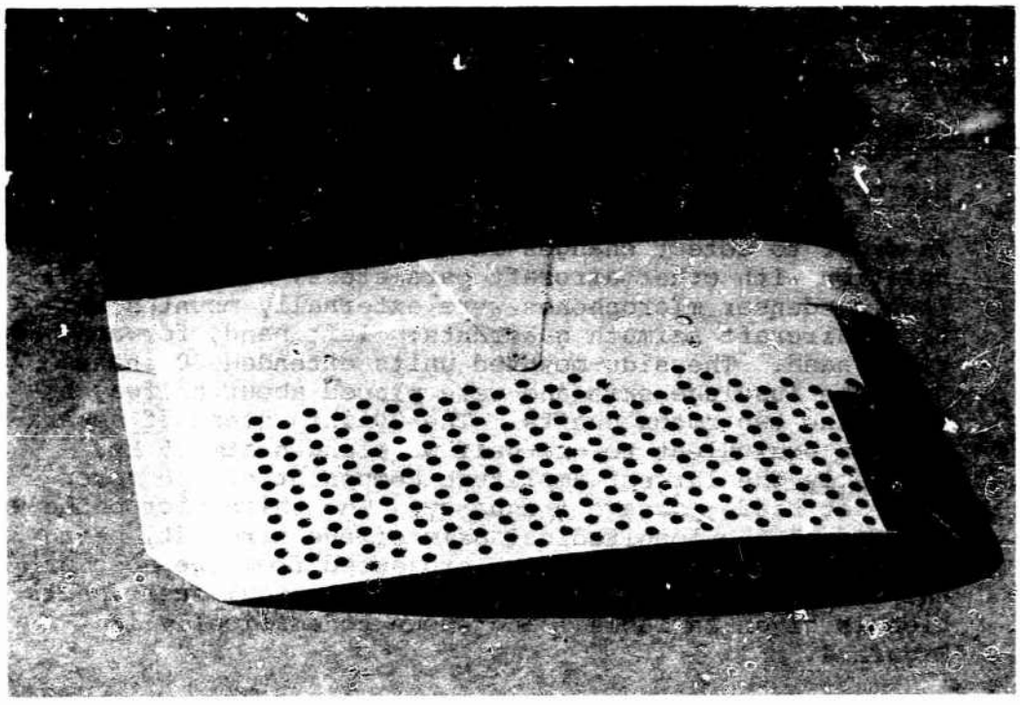



Figure 2. General Arrangement of CH-47A .



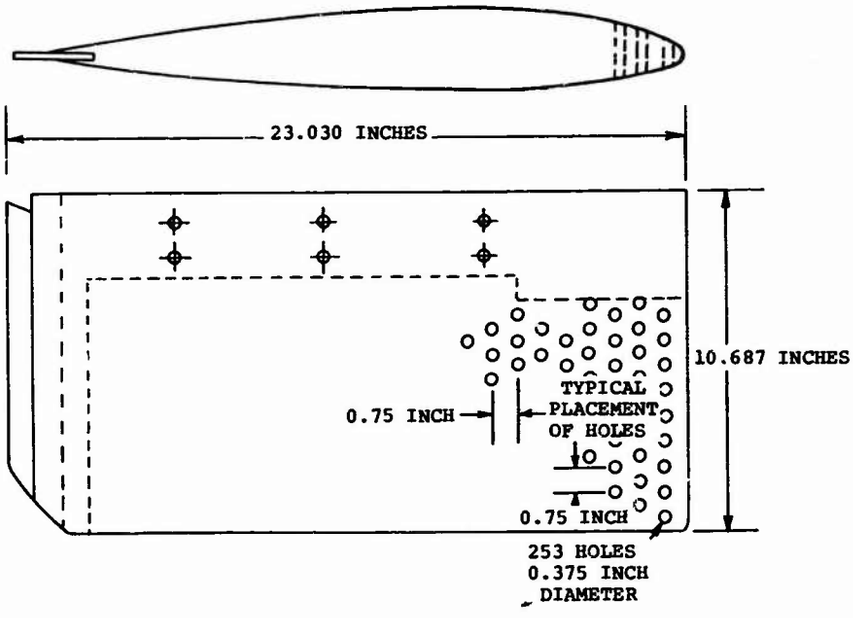



Figure 3. Details of Rotor Blade Porous Tip.

The modified blades including tips were teeter-balanced, tracked, and endurance-whirled on the whirl-tower facility. In addition, the blades were tracked on the aircraft prior to the flight test program. The final track was accomplished within production tolerances.

## INSTRUMENTATION - PHASE I

### 1. Microphones

In order to detect changes in rotor noise for a valid correlation with other aircraft parameters, sensitive 1/4-inch condenser microphones were externally mounted in three aircraft azimuth quadrants: left hand, forward, and right hand. The side-mounted units extended 30 inches from the fuselage skin and were placed about halfway between the two rotor shafts. The 30-inch standoff separation is equivalent to one-half wavelength at 225 Hz, generally the largest amplitude component of the rotor pulse at blade-passage frequency. The third microphone was located on the longitudinal axis of the aircraft, being placed on the yaw boom which projected from the nose of the aircraft. A complete list of acoustical instrumentation is given in Table I and shown schematically in Figure 4.

The microphone cartridge and cathode follower were mourted in polyurethane foam in U-clamps, in order to eliminate undesirable structurally induced noise. Positioning the longitudinal axis of the cathode follower parallel to the fuselage reference line lowered self-induced aerodynamic noise to a level well below that of the rotor noise at all airspeeds. Cockpit noise levels, which were also recorded, were somewhat higher than in production versions of the CH-47A, since much of the acoustical treatment was removed to permit routing of instrumentation wire packs. Condenser microphones were used for the airborne-measuring system because of their sensitivity and compactness; since they are fed by alternating current power supplies, they remain stable over long periods.

### 2. Recorder

The three external microphone channels were simultaneously recorded on three direct record channels of a four-channel 1/4-inch magnetic tape recorder. The fourth channel contained a record coder signal and recorded in the FM mode. The same record encoder used for the Reference 3 program was also used for all channels of acoustical data so that precise identification and time correlation could be obtained between the data of both programs.

TABLE I. LIST OF ACOUSTICAL INSTRUMENTATION

| Location | Instrument | Manufacturer | Model | Serial | Location |
|---|---|---|---|---|---|
| Airborne | DC-AC Inverter | Carter | - | - | - |
| External | Recorder Power Pack | Lockheed | 1031 | - | - |
| | Tape Recorder | Lockheed | 411CDF | 0149 | - |
| | Microphone Power Supply | Bruel & Kjaer | 2801 | 107728 | Left-Hand Side |
| | Microphone Power Supply | Bruel & Kjaer | 2801 | 107732 | Yaw Boom |
| | Microphone Power Supply | Bruel & Kjaer | 2801 | 107730 | Right-Hand Side |
| | Cathode Follower | Bruel & Kjaer | 2615 | 141513 | Left-Hand Side |
| | Cathode Follower | Bruel & Kjaer | 2615 | 141563 | Yaw Boom |
| | Cathode Follower | Bruel & Kjaer | 2615 | 141552 | Right-Hand Side |
| | Microphone | Bruel & Kjaer | 4136 | 101292 | Left-Hand Side |
| | Microphone | Bruel & Kjaer | 4136 | 141829 | Yaw Boom |
| | Microphone | Bruel & Kjaer | 4136 | 141755 | Right-Hand Side |
| | Nose Cone | Bruel & Kjaer | 0053 | - | All External |
| | Pistonphone | Bruel & Kjaer | 4220 | 85404 | - |
| Airborne | | | | | |
| Internal | Recorder Power Pack | Lockheed | 1031 | - | - |
| | Tape Recorder | Lockheed | 411C4D | 0168 | - |
| | Microphone Power Supply | Bruel & Kjaer | 2801 | 107731 | Cockpit |
| | Cathode Follower | Bruel & Kjaer | 2613 | 141231 | Cockpit |
| | Microphone | Bruel & Kjaer | 4131 | 123080 | Cockpit |
| | Pistonphone | Bruel & Kjaer | 4220 | 85404 | Cockpit |
| North Side | | | | | |
| of Runway | DC-AC Inverter | Terado | - | - | 200 ft |
| | Tape Recorder | Ampex | PR-10 | - | |
| | Cathode Follower | Bruel & Kjaer | 2630 | 144605 | |
| | Microphone | Bruel & Kjaer | 4131 | 136272 | |
| | Pistonphone | Bruel & Kjaer | 4220 | 107863 | |
| | Cathode Follower | Bruel & Kjaer | 2630 | 37607 | 600 ft |
| | Microphone | Bruel & Kjaer | 4131 | 78601 | |
| | Pistonphone | Bruel & Kjaer | 4220 | 107863 | |
| South Side | | | | | |
| of Runway | DC-AC Inverter | ATR | - | X-01337 | 200 ft |
| | Tape Recorder | Ampex | 672 | 1368 | |
| | Cathode Follower | Bruel & Kjaer | 2630 | 144620 | |
| | Microphone | Bruel & Kjaer | 4131 | 136277 | |
| | Pistonphone | Bruel & Kjaer | 4220 | 85372 | |
| | Cathode Follower | Bruel & Kjaer | 2630 | 102814 | 600 ft |
| | Microphone | Bruel & Kjaer | 4131 | 104788 | |
| | Pistonphone | Bruel & Kjaer | 4220 | 85372 | |

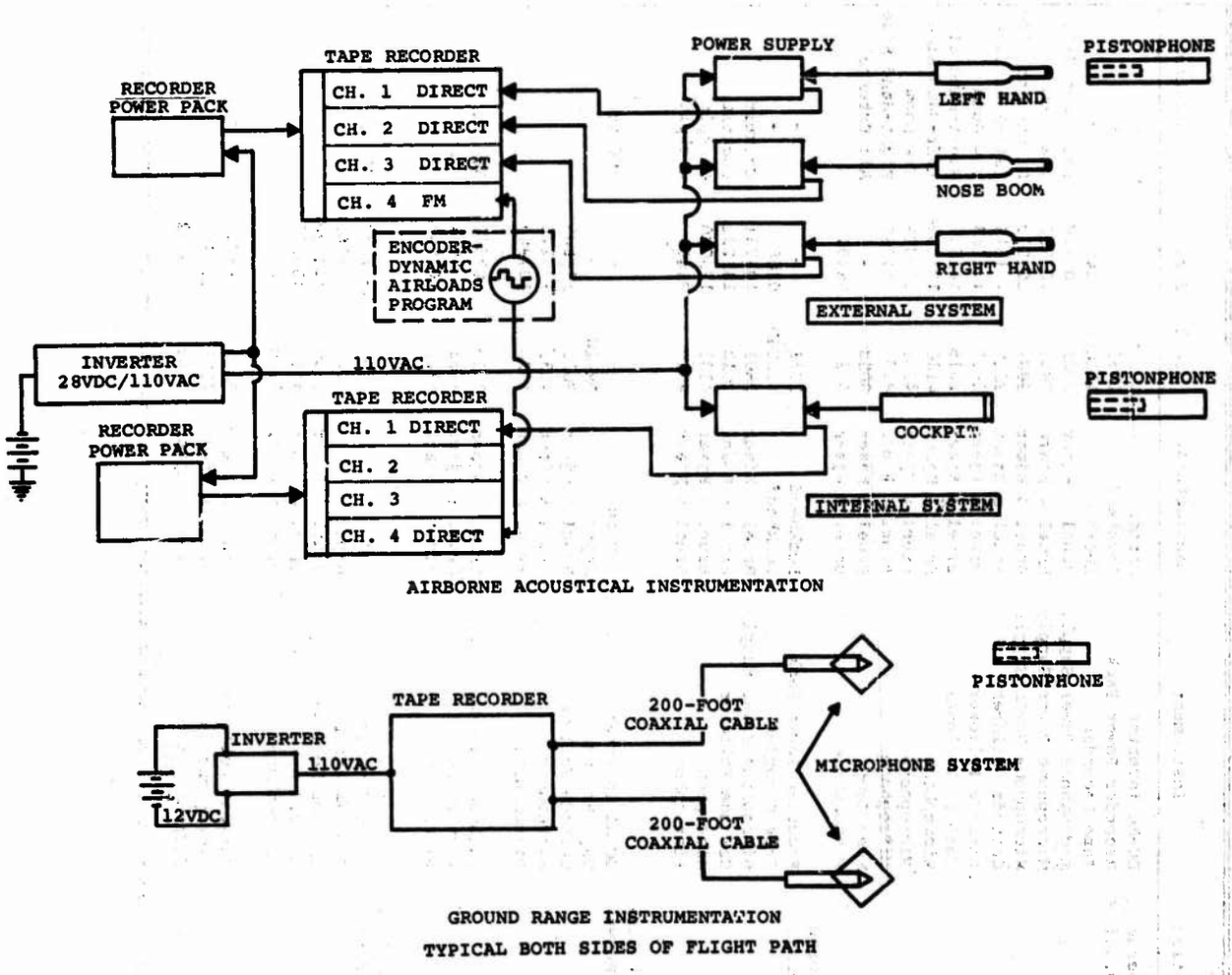



Figure 4. Schematic of Acoustical Instrumentation.

The cockpit microphone data were recorded on a tape recorder which was similar to that used for the aircraft external data and also contained a record identification code from the Reference 4 program instrumentation.

3. Calibration

Frequency response characteristics of the recording system are shown in Figure 5. These data have been determined from rms sine wave inputs and include microphone cartridge calibrations (obtained separately) and cable and recorder system response. Prior to and immediately following each flight, a single frequency tone (250 Hz) was applied to each system using a pistonphone calibrator which produces a 124-db rms level. Because the waveform characteristic of the rotor pulse is not sinusoidal, a response check was performed on the recording system using a comparison of input and output levels for a series of actual recorded pulses. This response is also shown in Figure 5. This type of peak-to-peak waveform input has a flatter response curve in the low frequency (31.5 and 63 Hz) and high frequency (8,000 Hz) regions; therefore, it is more directly applicable to the subject analysis. However, the conventional rms calibration corrections were applied to the data, since this is a recognized calibration procedure and is traceable to standards.

INSTRUMENTATION - PHASE II

1. Microphones

To evaluate the effect of porous tips on external rotor noise of the aircraft, a ground range of microphones was erected and the helicopter was flown over them at low altitudes. Four 1-inch condenser microphones were arranged as shown in Figure 6 for the ground range array. The microphones at 600 feet provided a somewhat less critical transient during fly-over than did the microphones at 200 feet, which were located a short distance inside the acoustic far field.

With ground instrumentation, the absolute change in noise levels could be evaluated even with shifts in azimuth of the noise with respect to the aircraft involved. This would not necessarily be the case with the aircraft instrumentation used for the subject program, since any shift in azimuth of the noise produced by the porous tip might not be fully detected by the microphones mounted on the fixed booms of the near field. The limitations of the ground range instrumentation are that the samples of data obtained are rather limited in time, and analysis of the data must necessarily be of a transient phenomenon. This is discussed more fully under Data Reduction and Analysis.

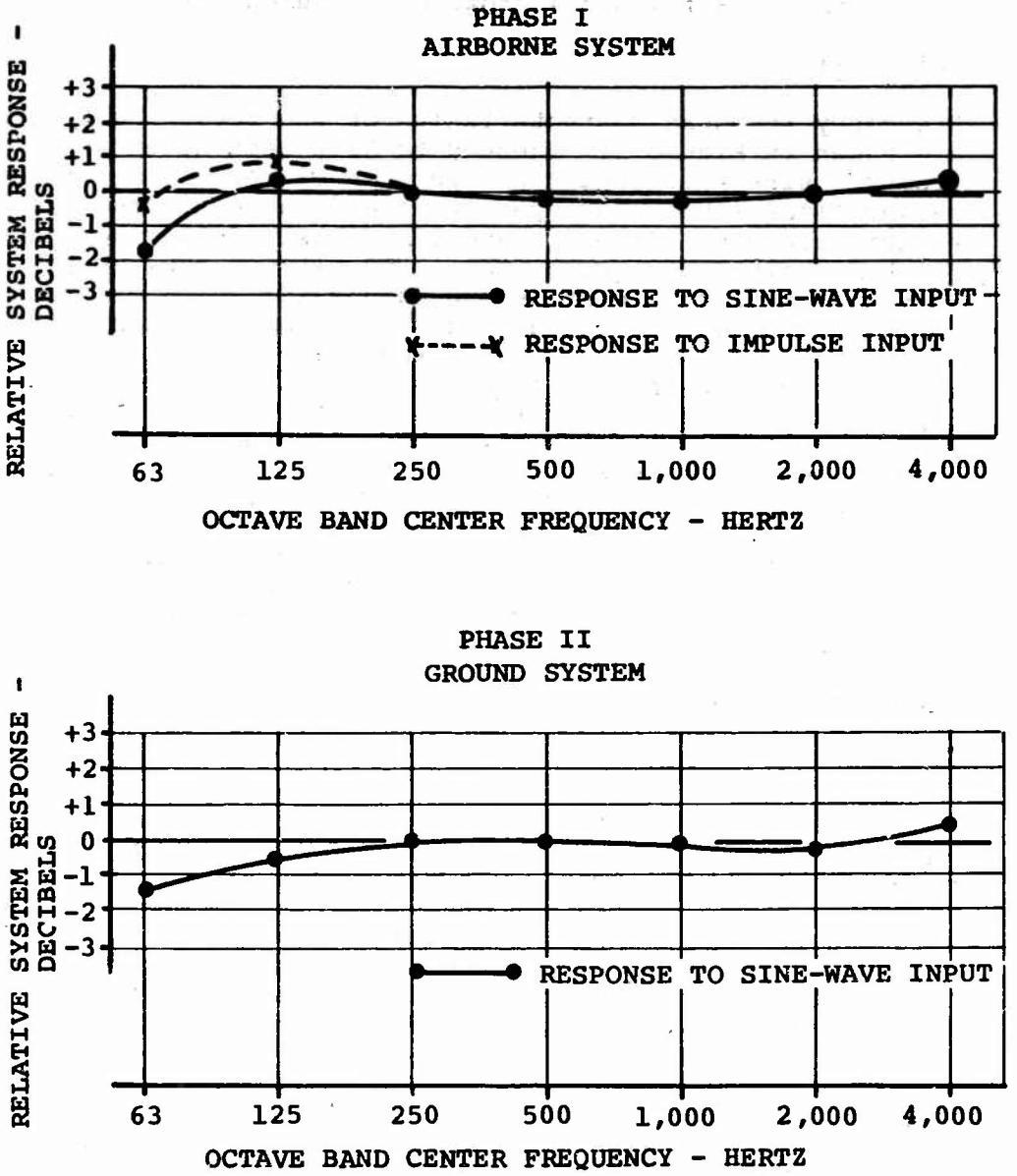
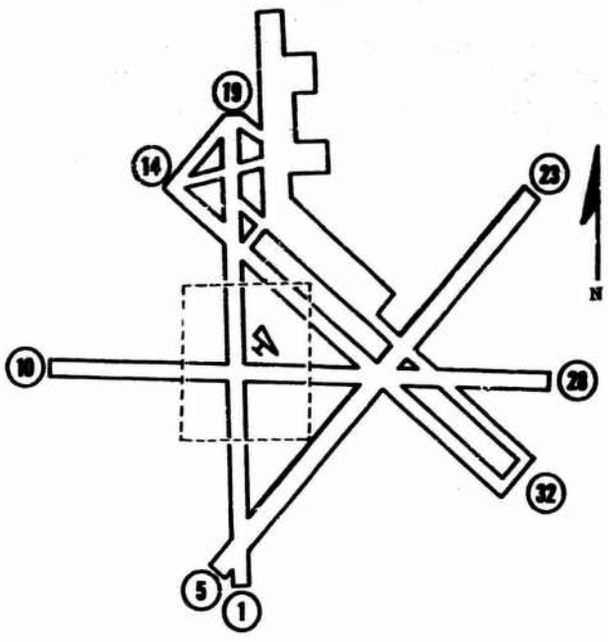



Figure 5. Record System Calibration Curves.

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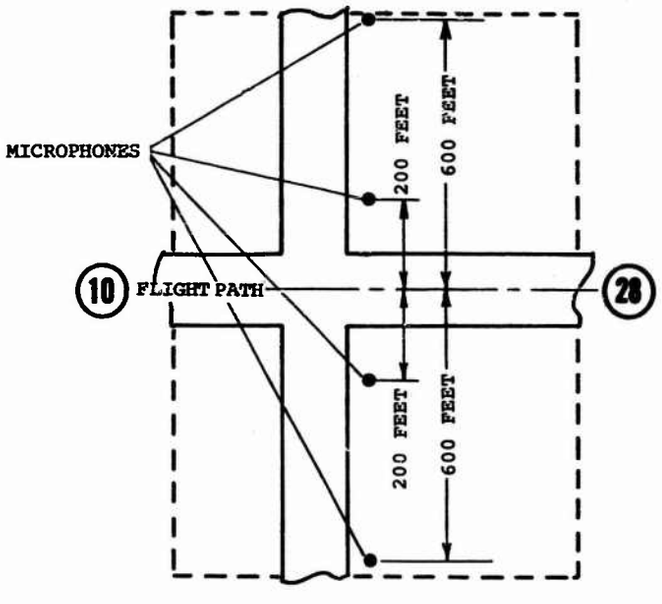


Figure 6. Phase II Test Site and Ground Range Microphone Array.

2. Recorder and Calibration

Frequency response characteristics of the recording systems are shown in Figure 5 (Phase II). These data were determined from sine-wave inputs and include microphone cartridge calibration (obtained separately) and recorder response. In the field, a single frequency (250 Hz) was applied to each system prior to and immediately following each flight program. An additional calibration correction was applied in order to correct for galvanometer frequency response. The airborne instrumentation was the same as that used for Phase I.

TEST PROGRAM - PHASE I

The Phase I test program consisted of measuring internal and external noise levels concurrent with the Reference 3 program which investigated variations in rotor speed, airspeed, gross weight, and longitudinal cyclic trim control.

The range of test conditions at which data were obtained was:

| | |
|---|---|
| Gross weight | 23,600 to 36,900 pounds |
| Airspeed | 0 to 148 knots |
| Rotor speed | 202 to 241 rpm |
| Fwd rotor cyclic trim | 0 to 3 degrees forward |
| Aft rotor cyclic trim | 0 to 5 degrees forward |
| Maneuvers and level flight | |

Specific points are defined in Appendix II.

TEST PROGRAM - PHASE II

The purpose of the Phase II test program was to evaluate the effect of porous blade tips on rotor-generated noise over a range of airspeeds and cyclic trim positions. Specific flight conditions are listed in Appendix II. Data on the reference flight were obtained with standard blade tip covers having the form of one-half of a body of revolution generated with an airfoil shape. The fully instrumented rotor blades of the Reference 3 program were utilized for this flight so that blade pressures were obtained.

For the hover conditions, the aircraft was in ground effect with a wheel height of approximately 5 feet. Surface winds were less than 5 knots.

For the fly-by program, the aircraft was flown at an altitude of 200 feet over the test range and maintained in a stabilized level flight condition for a minimum of 1,000 feet prior to and beyond the ground microphone array. To determine what effect minor irregularities in aircraft altitude, course, and gross

weight would have on the data acquired throughout the program, four 120-knot fly-bys were performed over the time span of the flight test: two were made at the beginning of the program, one was made at the midpoint, and one was made at the completion of the test. In addition, the effect of ambient winds on rotor-generated noise was investigated by reversing the direction of the aircraft over the course. These effects were minor.

For the approach and flare condition, the landing spot was on the axis of the ground range midway between the left-hand and right-hand microphones. For the maximum rate-of-climb point, the aircraft approached the range at an altitude of 200 feet and began its climb such that when passing over the microphone an altitude of 500 feet had been obtained.

Flight testing with the porous tips was carried out in the same order as with the standard tips in order that the effect of the porous tip could be evaluated at the same gross weight.

## DATA REDUCTION AND ANALYSIS

### Dynamic Airloads Data

Because of the large amount of instrumentation installed on the aircraft for the Reference 3 program, it was necessary to share the available channels of recording equipment on a time basis; thus, the forward and aft rotor blade instrumentation were sequenced on alternate rotor cycles so that a specific pressure gage on the forward rotor, for instance, time-shared the same recording channel with the respective gage on the rear rotor. The analysis under consideration included five rotor cycles distributed through twenty cycles of data. Results were presented as maximum, minimum, and mean values of the variable. The mean value was used for all correlations in this report. A detailed description of the instrumentation system and analysis methods can be found in Reference 3.

### Acoustical Data

Each channel of external microphone data was analyzed by frequency spectrum using full octave bandpass filters of the "preferred" frequency limits[5]. Since circuit ringing can occur when pulse-loading characteristics of rotor noise are filtered through bandpass filters, an investigation to ensure against these false indications was performed.

A representative sample of banging rotor noise was stripped out on an oscillograph using both full octave and one-third octave bandpass filters for that sample. The levels in each group of three one-third octave filters corresponding to the full octave

filter over that frequency range were summed and compared with the level in that equivalent full octave. In each instance the sum of the levels in the one-third octaves was identical with the full octave level; presumably, had any one of the filters been ringing, the sound pressure amplitudes would not have been identical.

An oscillographic readout system was used for this program in order to examine the high rates of pressure changes associated with rotor noise. All external aircraft microphone channels were stripped out through bandpass filters which have geometric centers at the following frequencies: 63, 125, 250, 500, 1,000, 2,000, and 4,000 Hz. Sound pressure levels above 5,600 Hz have not been reported since the galvanometer selected for data stripouts, which give maximum amplitude over the broadest frequency range, did not respond to these high frequencies. Restripping with a high frequency galvanometer was not considered necessary since the problems were completely defined by frequencies below 5,600 Hz. Other analyses and display systems were considered but were rejected since they did not authentically display the rotor bang waveform. Simultaneous stripout of the three airborne external microphones was performed for the overall frequency records as shown in Figure 7.

Acoustical Data - Phase II

The airborne data, both internal and external, were treated similarly to data from the Phase I program.

The transient nature of the data resulting from aircraft flown over a fixed ground array of microphones requires a completely different approach to analysis. While the maximum value of the fly-by is useful, it does not relate changes in characteristics which take place prior to and after the fly-by; namely, the rate of buildup and decay of sound pressure. Thus, while two aircraft may have the same maximum level, if the pressure reading on the microphone builds up and decays slowly, this implies a high sound level over a relatively long period, whereas rapid buildup and decay characteristics imply short periods of exposure. This affects both detection and annoyance of the aircraft.

Another aspect of the exposure time which is unrelated to physical changes in the aircraft is the airspeed at which it passes over the ground range. To account for this, a fixed distance was selected as the basis for evaluation of the data, and after consideration of some representative samples of data, this distance was selected as 400 feet (250 feet before maximum and 150 feet following the maximum level), since the amplitude of the data appeared to be reasonably flat over this range. The magnitude of each pulse at blade-passage frequency was tabulated over the time period corresponding to the noted

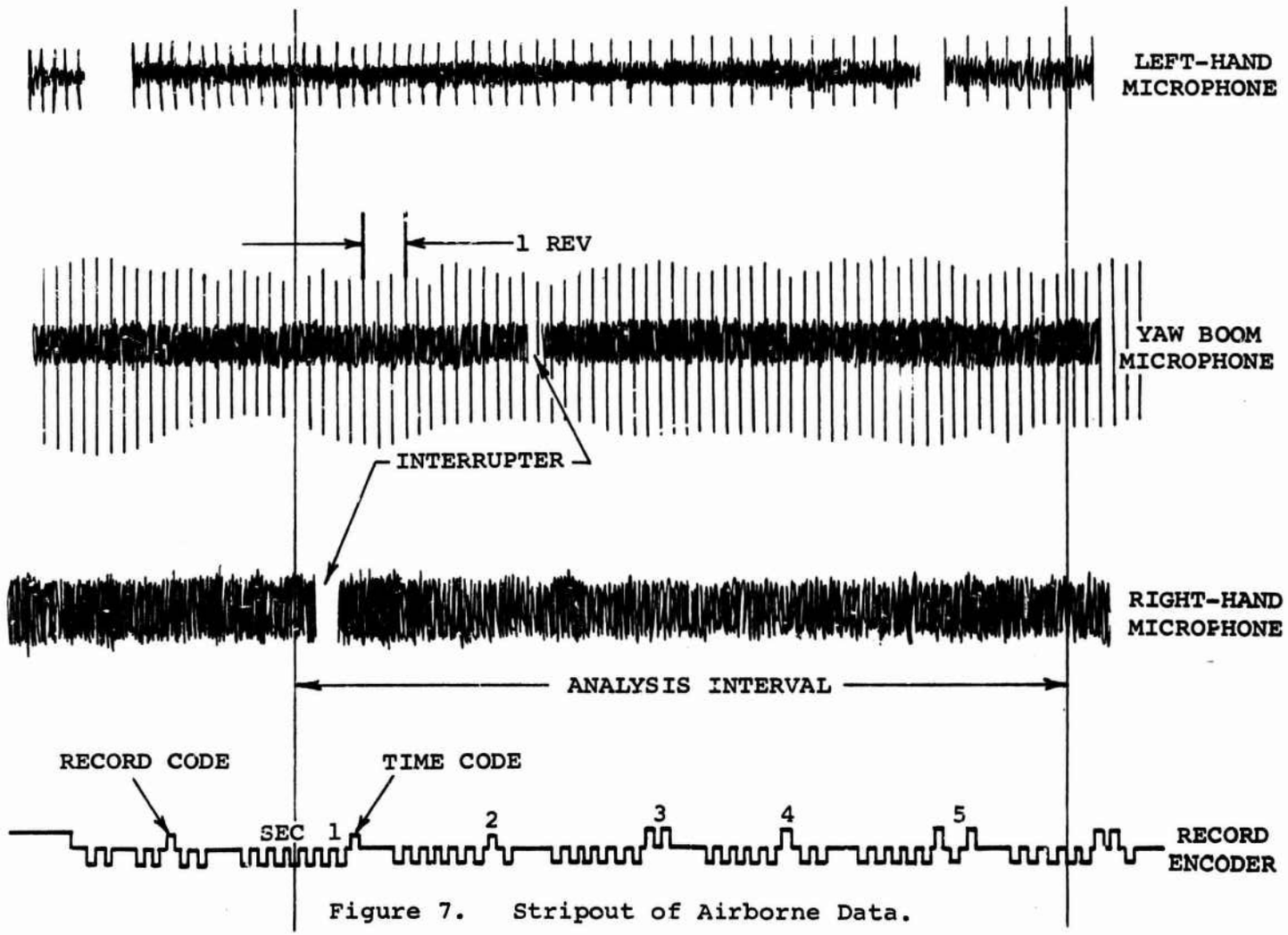


Figure 7. Stripout of Airborne Data.

sample, and the mean value of these amplitudes was computed; this result, then, is the value which has been reported and used for correlation studies.

## Statistical Analysis

A large portion of the noise data gathered during the subject program was to be correlated with other variables and parameters obtained from dynamic airloads instrumentation; the only time interval (when the sound pressure levels were read) was the identical interval over which the Reference 3 program data were analyzed, namely, the initial 5 seconds of record (see Figure 8). The peak amplitude of the three-per-revolution rotor bang period was used for correlation purposes. In order to achieve an efficient procedure for determining the representative value for each run, a statistical investigation was then made of several representative flight conditions. The results are presented in Table II.

Data from each of the three external airborne channels were examined. For the same time interval of analysis as the dynamic airloads data, the peak magnitude of every pulse at blade-passage frequency was tabulated and the values of the mean, median, and mode were calculated.* These values were then compared with an average value determined from one-half the sum of the maximum and minimum levels for each run. The absolute value of the difference of the arithmetic mean and average value was found to differ, in general, by less than 0.5 db.

For the two instances noted where this difference exceeded 0.5 db, the data appeared to be bimodal; that is, there was an interval in the record in which banging occurred and another interval in which banging did not occur because of unsteady conditions for that record. In both cases, the indicated airspeed was approximately 51 knots. Further confidence in the grouping of data was noted in the closeness of the mean, median, and mode; these, along with the standard deviation, are shown in Table II. It was concluded that a measure of the mean value of the data, generally within 0.5 db, could be obtained from the average value determined from one-half the sum of the maximum and minimum for each run. All data for each airborne microphone and run were then tabulated, corrected for frequency-response characteristics of the recording and playback system and oscillograph galvanometer response, and then used as input to a computer program which calculated the mean value of all data points.

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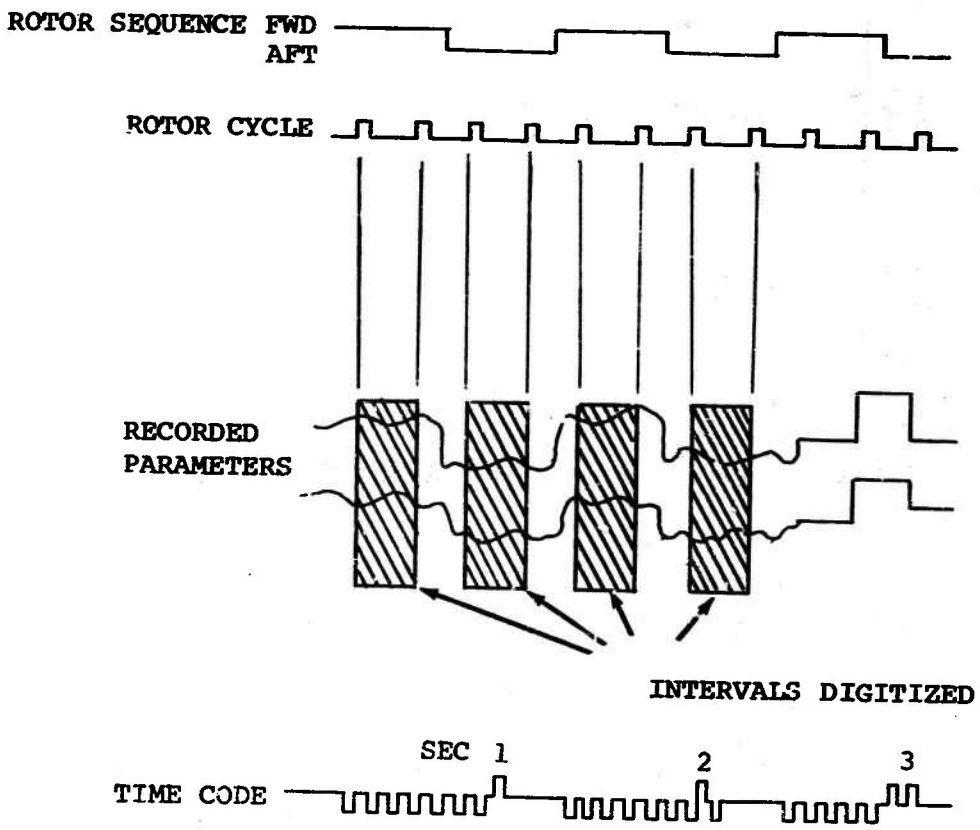
* Mean - arithmetic mean.
Median - equal number of pulses above as below this value.
Mode - amplitude which occurs most frequently.




NOTE: SEE REFERENCE 3,
VOL. III, FIG. 3

Figure 8. Selection of Flight Data for Digitizing.

TABLE II. STATISTICAL ANALYSIS OF AIRBORNE DATA

| Microphone | Record No. | Approx Gross Weight (lb) | True Airspeed (kn) | Mean (db) | Average (db) | Median (db) | Mode (db) | Standard Deviation (σ) |
|---|---|---|---|---|---|---|---|---|
| | | | | FLIGHT 393 | | | | |
| Left | 6 | 36,000 | 28 | 125.6 | 125.5 | 127 | 127 | 0.76 |
| | 12 | 36,000 | 63 | 124.8 | 125 | 126 | 126 | 1.52 |
| Nose | 6 | 36,000 | 28 | 122.5 | 123 | 123 | 122 | 2.23 |
| | 12 | 36,000 | 63 | 124.5 | 124.5 | 125 | 125 | 1.19 |
| Right | 6 | 36,000 | 28 | 126.5 | 127 | 127 | 127 | 1.17 |
| | 12 | 36,000 | 63 | 125 | 125 | 126 | 126 | 1.73 |
| | | | | FLIGHT 394 | | | | |
| Left | 1 | 32,500 | 58 | 126.8 | 127.6 | 128 | 130 | 2.48 |
| | 2 | 32,500 | 101 | 125 | 125.5 | 126 | 125 | 0.83 |
| | 3 | 32,500 | 85 | 126 | 126.5 | 127 | 127 | 1.75 |
| | 11 | 32,500 | 28 | 124.5 | 124 | 125 | 125 | 1.18 |
| Nose | 1 | 32,500 | 58 | 128.8 | 130 | 130 | 130 | 1.23 |
| | 2 | 32,500 | 101 | 129.6 | 130 | 130 | 131 | 1.72 |
| | 3 | 32,500 | 85 | 129 | 129 | 130 | 129 | 1.79 |
| | 11 | 32,500 | 28 | 124.5 | 124.5 | 124 | 125 | 1.58 |
| | | | | FLIGHT 395 | | | | |
| Left | 3 | 23,500 | 54 | 126.9 | 125.5 | 128 | 128 | 1.90 |
| | 9 | 23,500 | 96 | 127.5 | 127 | 127 | 126 | 1.57 |
| Nose | 3 | 23,500 | 54 | 127.5 | 127 | 127 | 127 | 1.80 |
| | 9 | 23,500 | 96 | 128.6 | 128.5 | 129 | 130 | 1.49 |
| Right | 3 | 23,500 | 54 | 125.9 | 126 | 126 | 125 | 1.59 |
| | 9 | 23,500 | 96 | 125.6 | 126 | 125 | 125 | 0.98 |

The program for calculating mean values also generated a data listing, which was scanned for check purposes prior to plotting; it also produced a magnetic tape which was input to an automatic data plotter. With the large quantity of data obtained in this program, it was judged expedient to review all data for consistency; thus, all airborne data acquired during the program were reviewed by an acoustical engineer not previously associated with the subject program. This procedure is recommended for all large data acquisition programs.

Cockpit internal noise levels were treated from a somewhat different approach, since internal noise was dominated by dynamic components, particularly in the test aircraft used for this program. Because of the large number of wire packs and cables which were required for the extensive instrumentation of the Reference 3 program, the normal acoustical treatment was removed from the aircraft. The internal noise was determined by full-octave spectrum analysis using a graphic level recorder for display.

## DISCUSSION OF RESULTS

## CORRELATION OF ACOUSTIC AND DYNAMIC AIRLOAD DATA - PHASE I

### Selection of Data for Correlation

The data parameters of the Dynamic Airloads Program selected for correlation with sound levels measured during the subject program either made a direct contribution to the generation of rotor noise or apparently resulted from the same source.

The three microphones, which were mounted externally to the aircraft, recorded the total acoustical output of the rotor system. Although all of the data from each of the microphones were analyzed for all test conditions (as reported in Appendix III), the following octave bands and microphone locations were selected for purposes of technical discussion:

1. Rotational Noise - 63 Hz

   This octave band is set by the primary pressure fluctuations caused by thrust torque and blade thickness, commonly called rotational noise, and also by low-frequency components of blade slap.

   Since the two side microphones sense both of these sources, while the nose-boom microphone did not sense blade slap at 63 Hz, the latter is used for all analyses of rotational noise.

2. Blade Slap - 250 Hz

   In much of the correlation of blade slap with other parameters of flight, the sound-pressure amplitude of the band-pass filter centered at 250 Hz was used; the following paragraph established the basis for this selection.

   Determination of differences in spectral content of waveforms with highly transient characteristics such as blade slap is a problem which does not readily yield to solution by ordinary means of analysis. As indicated previously, existing graphic level recorders do not have the ability to respond to rise factors* greater than 5; rotor noise rise factors are generally of the order of 15. Wave analyzers, on the other hand, lend themselves to static

* Ratio of peak pulse amplitude to width.

or quasi-static functions, but the effective tape-slowing techniques which are required for this type of analysis result in loss of quality in the data. Selection of the 250-Hz band as a primary indicator of blade slap was verified by performing a numerical harmonic analysis of a slapping and nonslapping waveform (Figure 9). Figure 10 shows that the greatest difference between the two sets of data is characterized by the range between the 15th and 30th harmonic of blade passage. The 250-Hz octave band is well centered in this range and was therefore selected as a simplified measurement of blade slap. Figure 11 is an octave band analysis of a banging and nonbanging rotor and supports the use of this octave for comparative purposes. Since the left-hand microphone responded to blade-slap noise at 250 Hz more strongly than the other two, because of directivity effects, data in this octave band will be presented for the left-hand position only.

3. High Frequency - 4,000 Hz

The high-frequency end of the spectrum is set by blade slap, when it occurs, and has a minimum readable level which is a function of wind noise and dynamic component noise. Although these high-frequency blade-noise levels are not as large in amplitude as the fundamental blade-slap frequencies, it is the existence of these higher harmonics which gives the blade bang a characteristic sharp sound which is an indicator of listener response. Here again, data from the left-hand microphones are presented as being the best indicator of blade slap.

Blade Pressure Time History

The primary purpose of the Dynamic Airloads Program was the measurement of rotor airloads. Since rotor noise levels at the microphone positions are simply rotor-generated oscillatory pressures which have propagated from the blade, a correlation of the strength of the source and position of the blades at the generation of the disturbance can be directly obtained from a study of blade-pressure time histories.

One forward and one aft rotor blade were instrumented for the airloads program with 54 surface-mounted pressure gages on each blade. The blades were positioned on the rotors so that the instrumented rear rotor blade immediately followed the instrumented forward blade and thus permitted a comparison of the effects of the wake of the front rotor on the rear. The processing of data has been described in detail in Volume III of Reference 3, but it should be noted that the data shown in the illustrations have a rather low upper frequency limit. This limitation results from the harmonic analysis procedure which

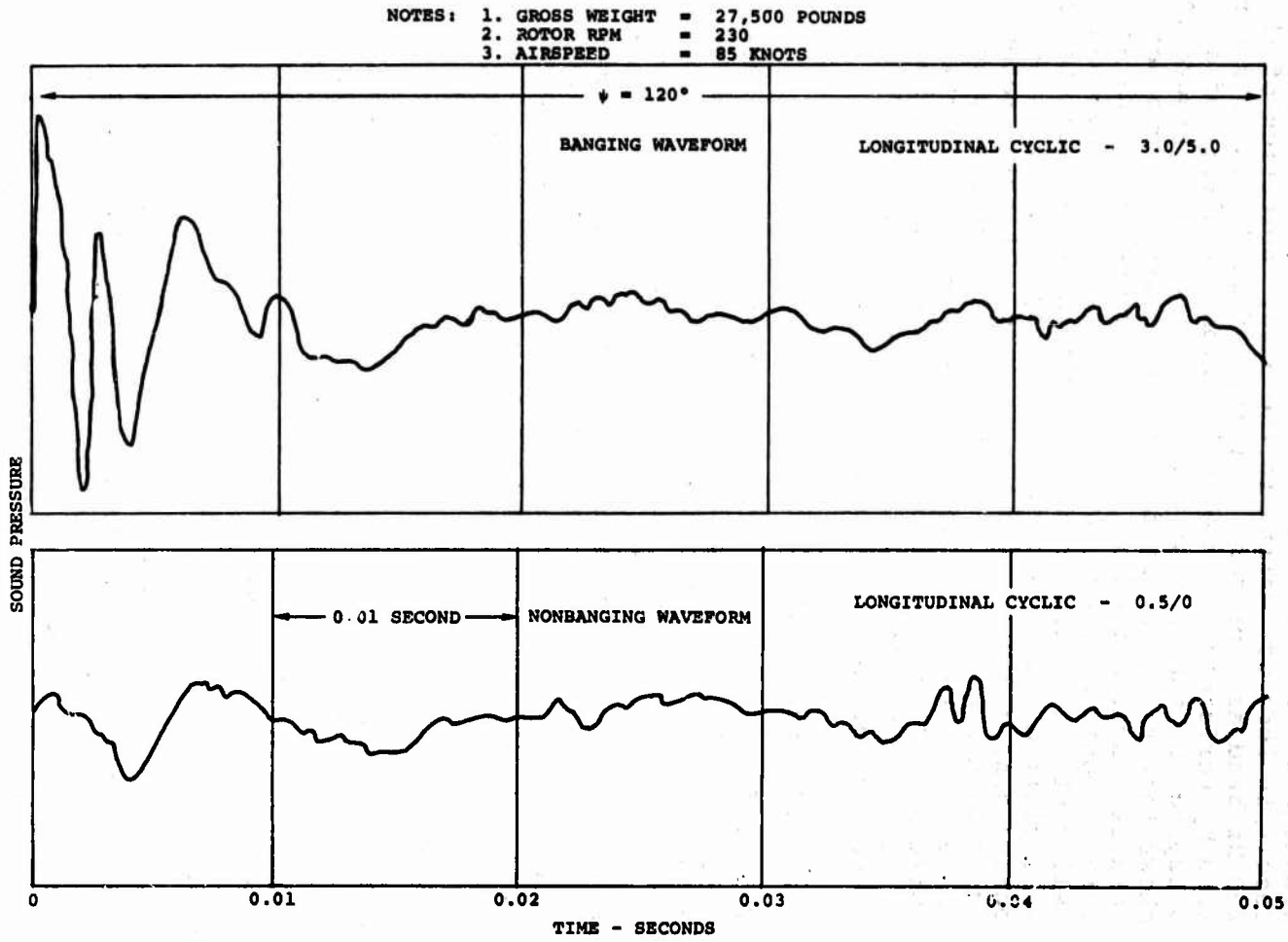



Figure 9. Waveform of Banging and Nonbanging Rotor.

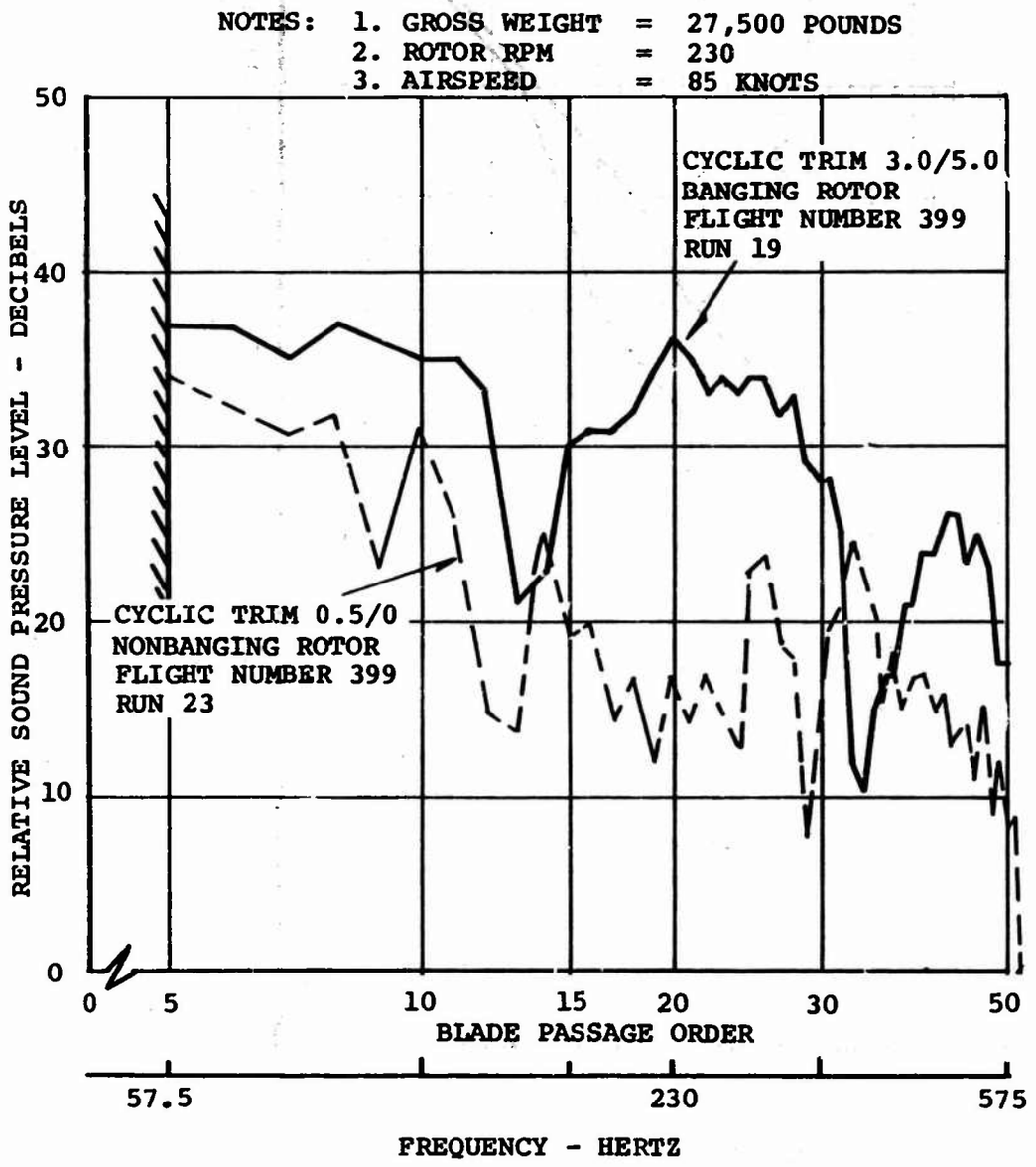



Figure 10. Digital Fourier Analysis of Rotor Blade Noise.

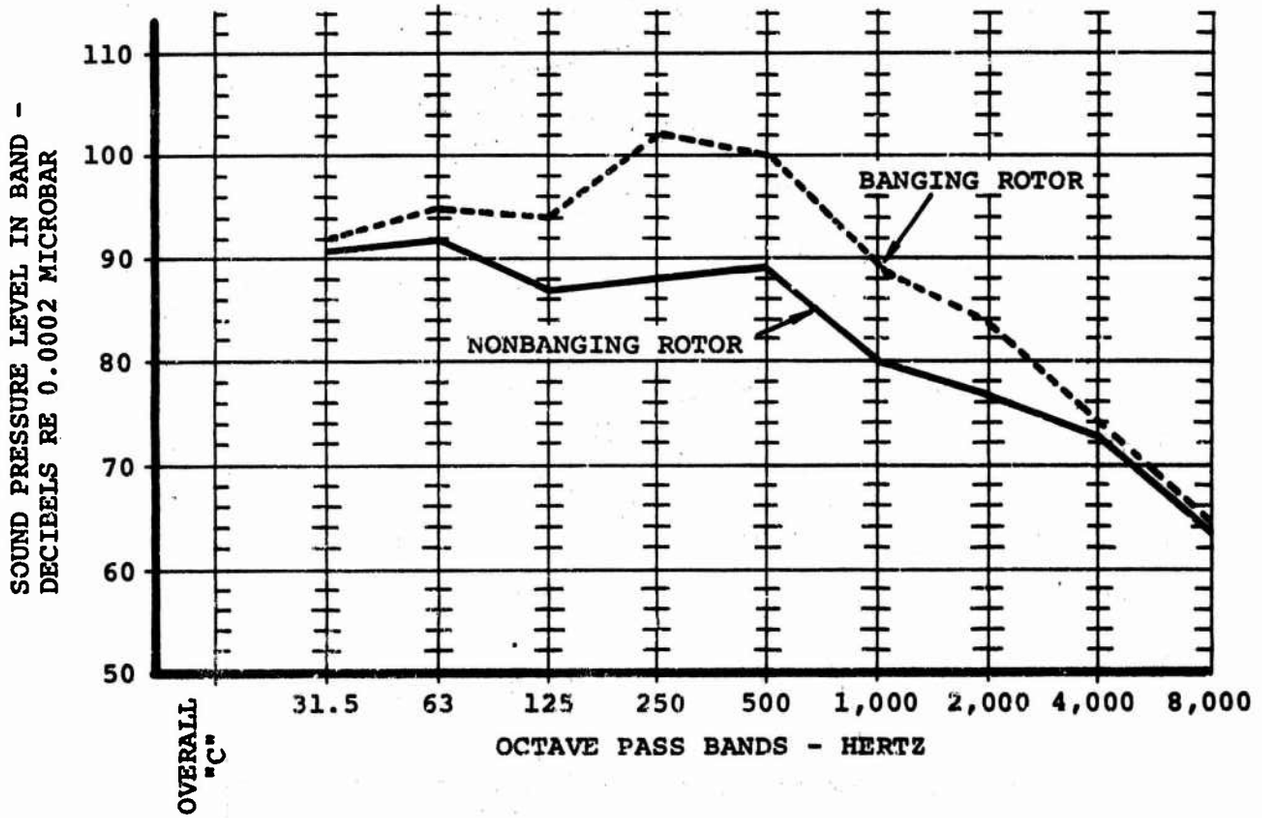



Figure 11. Octave Band Spectra of Helicopter in Forward Flight.

digitizes the rotor cycle at a rate of 250 ordinates per second. Since a minimum of four ordinates was utilized to describe any specific waveform, the highest frequency which may be reliably observed was limited to 60 Hz. The digitizing of the pressure waveform was performed for 5 nonconsecutive rotor cycles over a total elapsed period of 20 rotor cycles, as indicated in Figure 8. Nonconsecutive rotor cycles were required since the records were alternately sequenced between forward and aft rotors; transition of rotor sequences occurred between the digitized cycles. The values were then averaged for the five cycles, corrected for phase shift and plotted on an automatic data plotter. The time histories which are illustrated in Figures 12 and 13 report pressures outboard of 0.75R for a forward and aft blade, respectively. Since the largest variations in pressures occur on the aft rotor, a chordwise distribution of time histories is illustrated for that rotor in Figure 14. As would be expected, the leading edge of the blade experiences the largest magnitude low-frequency pressure fluctuation, and all of the pressure data reported herein are either at X/C = 0.02 or X/C = 0.9, depending upon the availability of complete data for a series of flight records. Figure 15 (Sheets 1 and 2) illustrates forward and aft rotor blade pressures for several airspeeds and two longitudinal trims at 28,500 pounds gross weight. When the aft rotor tip path in the overlap area is trimmed (tilted) forward, as with extended trim (BITF/BITR = 3.0°/5.0°), the planes of the front and rear rotors cross, and the aft rotor intercepts the trailed tip vortex from the front rotor. This effect is particularly noticeable at 43 and 85 knots, where both extended and retracted trims (BITF/BITR = 0.5°/0°) are shown.

Blade Separation

It was noted that the most effective means of changing blade noise was through operation of the longitudinal cyclic trim system. As shown in Figure 16, this system's capability to differentially tilt the rotor disks affords a wide range of tip path separations, with retracted trims opening the gap between tip paths in the overlap region.

The separation of the rotor tip path planes at any rotor azimuth can be predicted from the aircraft geometry if the Fourier coefficients for harmonic blade flapping are known. Figure 17 shows the essential geometry for calculation of rotor blade tip path separation and the rotor azimuth locations used in calculations for the subject program. The height of the blade tip above the fuselage reference plan is established for each rotor. The total blade flapping angle $\beta$ (with respect to a plane parallel to the horizontal fuselage reference axis and passing through the rotor hub) is defined by

$$\beta = a_o - a_1 \cos \psi - b_1 \sin \psi + i_s \cos \psi \qquad (1)$$

where

$a_o$, a, and $b_1$ = harmonic blade-flapping coefficients

$i_s$ = rotor shaft angle with respect to a normal to the fuselage reference plane

$\psi$ = rotor azimuth angle

From this, the tip path separation normal to the free stream may be calculated:

$$H = h \cos \alpha_f = [(R \sin \beta_r + L_r) - (R \sin \beta_f + L_f)] \cos \alpha_f \qquad (2)$$

where

R = blade radius
L = pylon height above the fuselage reference plane
$\alpha_f$ = fuselage angle with respect to the free stream

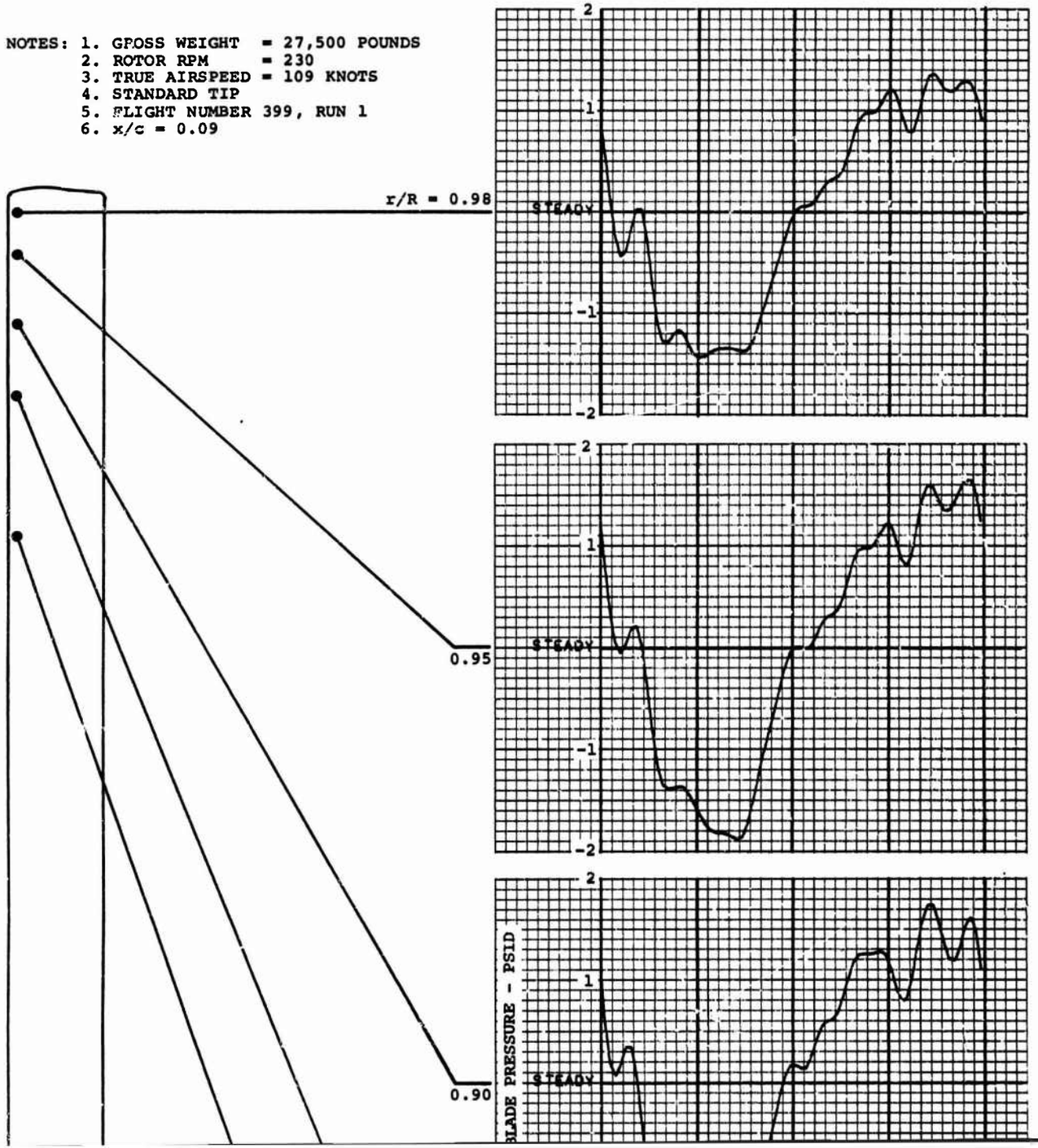
Measured inputs were utilized for values of longitudinal cyclic trim, the Fourier coefficients were calculated from an existing computer program[6], and the blade separation was determined from equations (1) and (2).

Figure 18 shows the effect of blade separation on a qualitative evaluation of blade noise and reveals that the tendency to bang is a function of the relative blade positions.

In general, there was a lack of nonbanging data recorded since the range of trims specified in the Dynamic Airloads Program did not include many cyclic trim combinations which avoid blade bang. During the Phase II portion of the program, however, a more systematic exploration of the effect of cyclic trim was performed, and these data are shown in Figure 19 for the 200-foot north-side ground microphone. As discussed previously, the 250-Hz band is the strongest indication of blade slap due to the interaction of a rotor blade and a trailed vortex. Examination of the 250-Hz chart of Figure 19 clearly shows the strong effect of blade separation.

D

NOTES: 1. GROSS WEIGHT = 27,500 POUNDS
2. ROTOR RPM = 230
3. TRUE AIRSPEED = 109 KNOTS
4. STANDARD TIP
5. FLIGHT NUMBER 399, RUN 1
6. x/c = 0.09



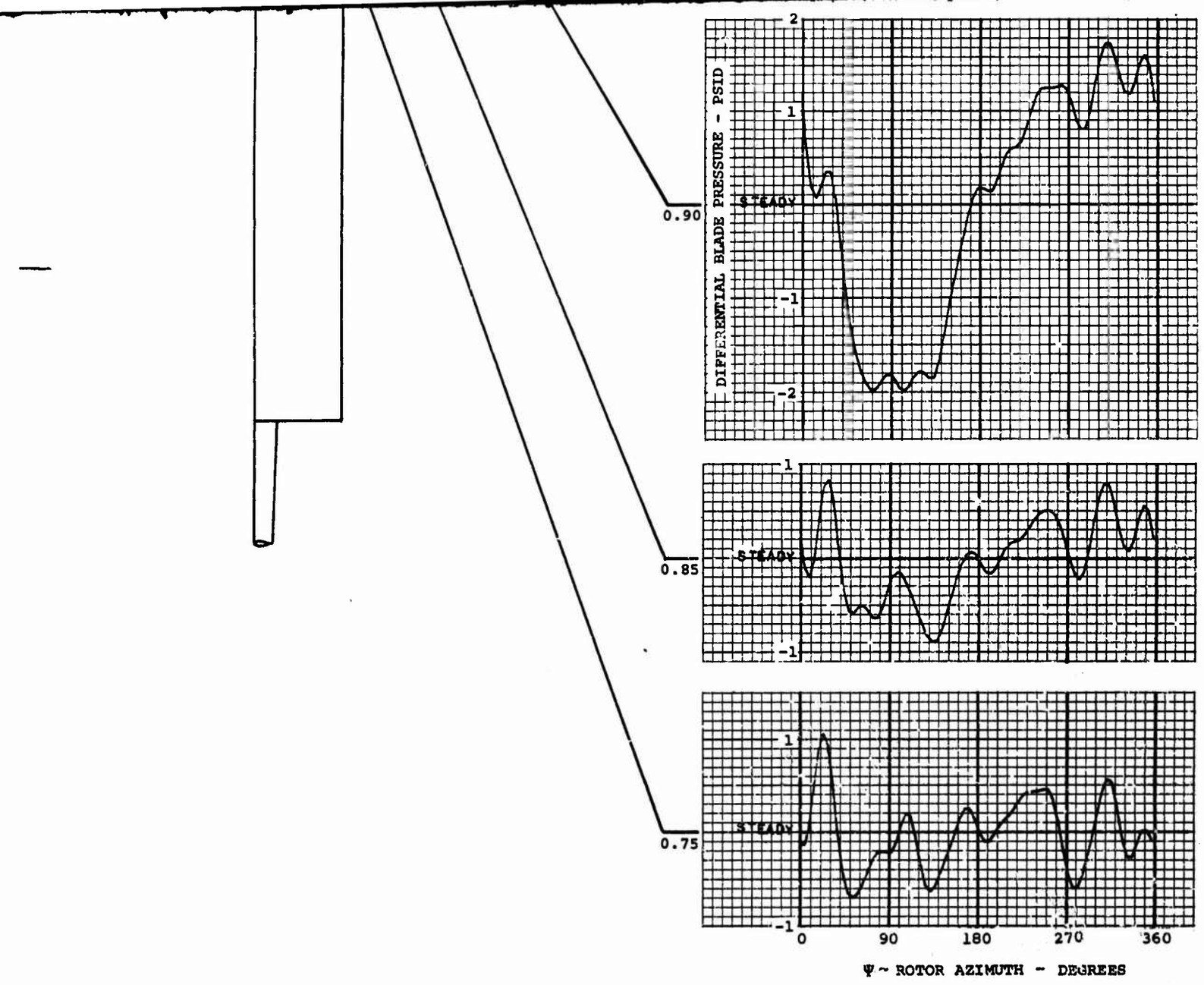
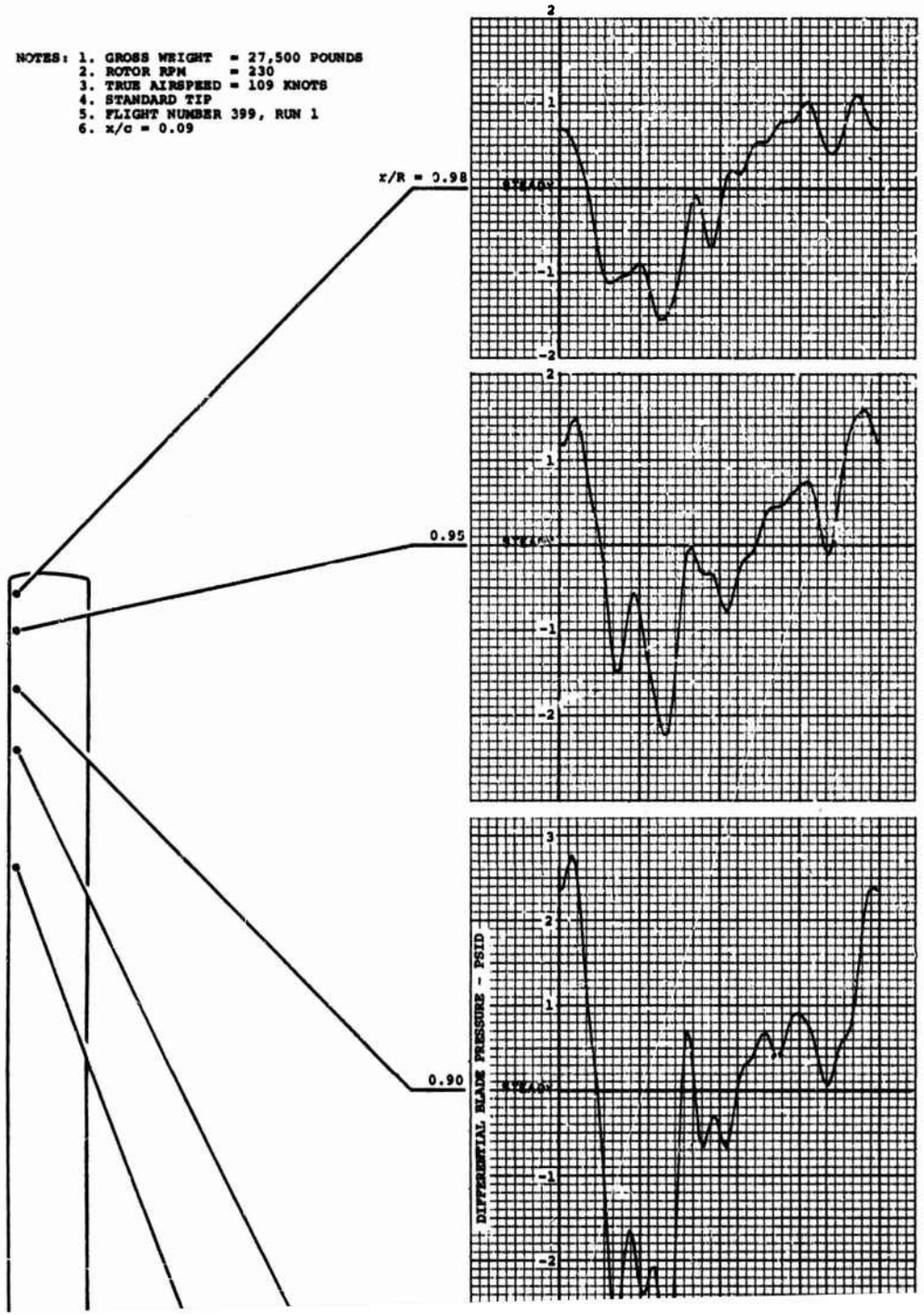



Figure 12. Spanwise Differential Pressure Time History - Forward Rotor.


NOTES: 1. GROSS WEIGHT = 27,500 POUNDS
2. ROTOR RPM = 230
3. TRUE AIRSPEED = 109 KNOTS
4. STANDARD TIP
5. FLIGHT NUMBER 399, RUN 1
6. x/c = 0.09
x/R = 0.98
0.95
0.90
DIFFERENTIAL BLADE PRESSURE - PSID
2
1
-1
-2
3

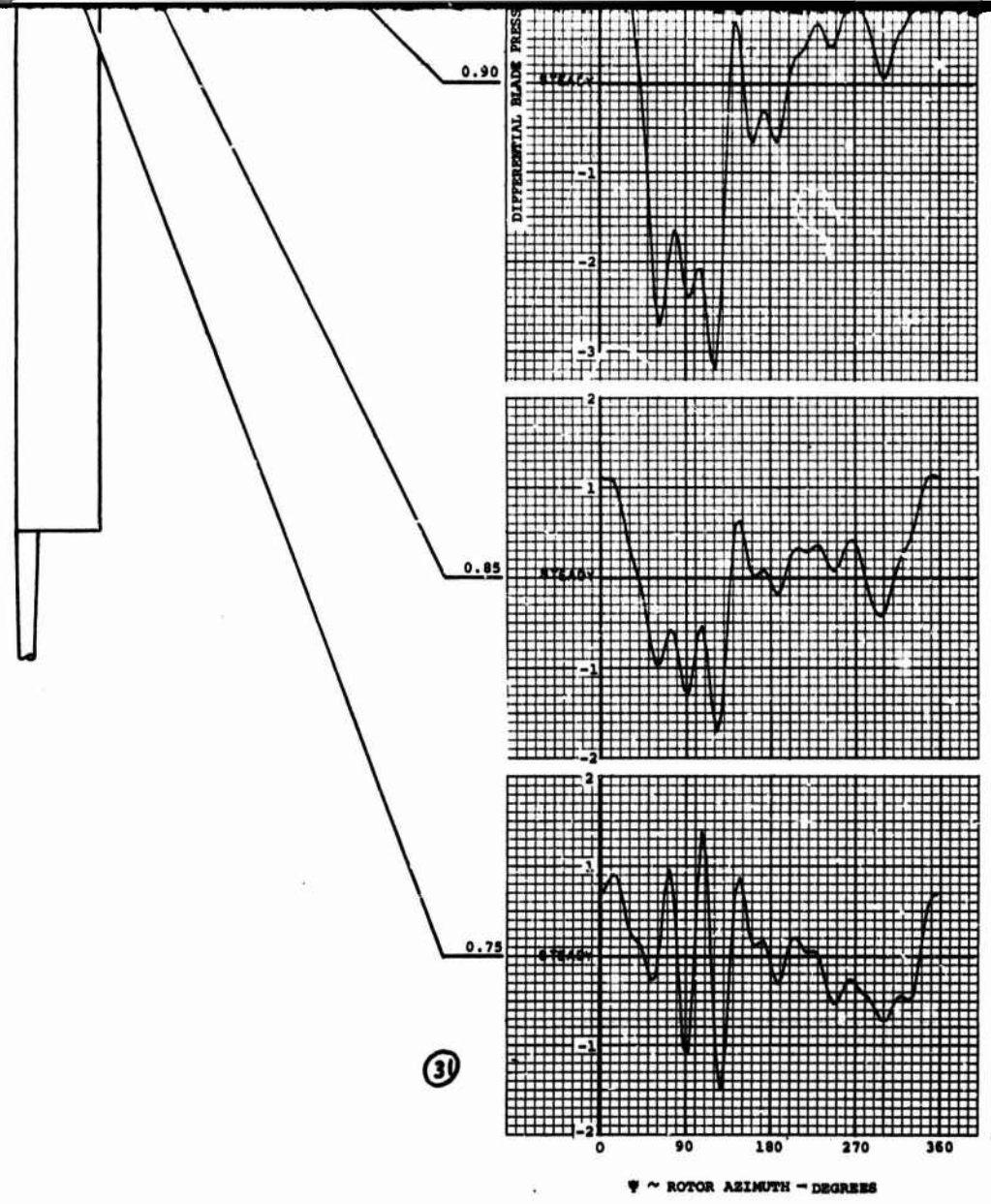
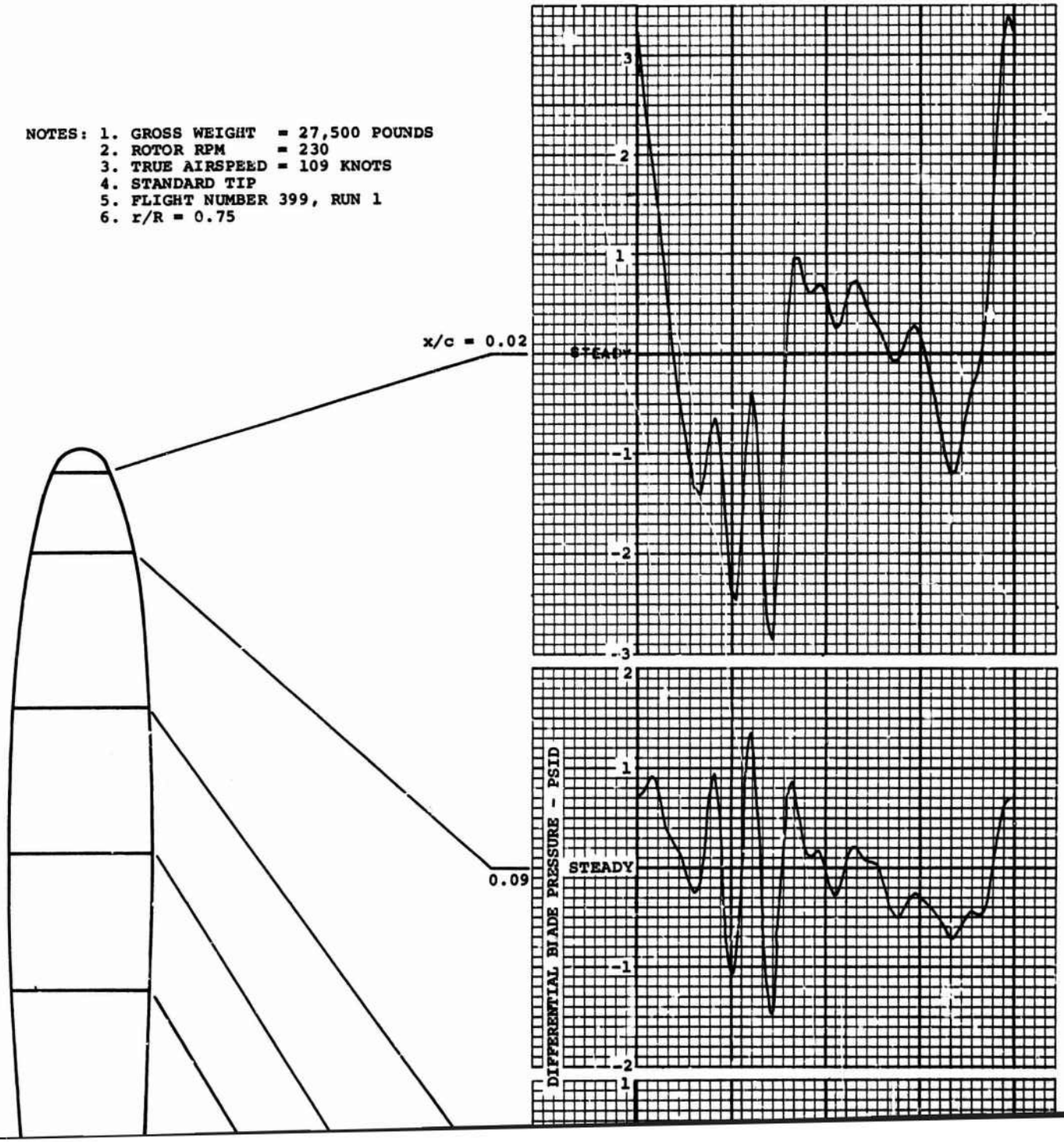



Figure 13. Spanwise Differential Pressure Time History - Aft Rotor.

NOTES: 1. GROSS WEIGHT = 27,500 POUNDS
2. ROTOR RPM = 230
3. TRUE AIRSPEED = 109 KNOTS
4. STANDARD TIP
5. FLIGHT NUMBER 399, RUN 1
6. r/R = 0.75



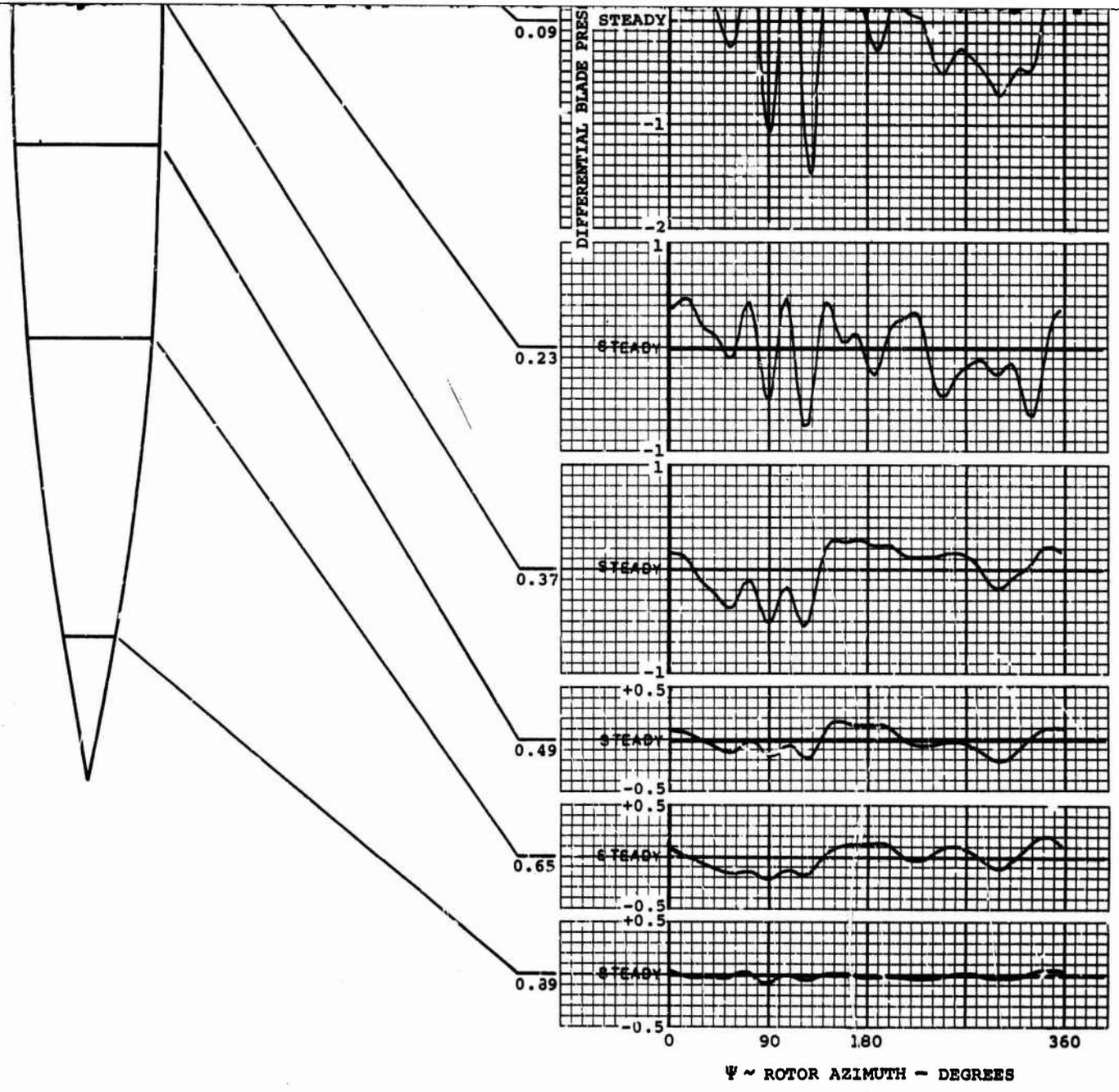
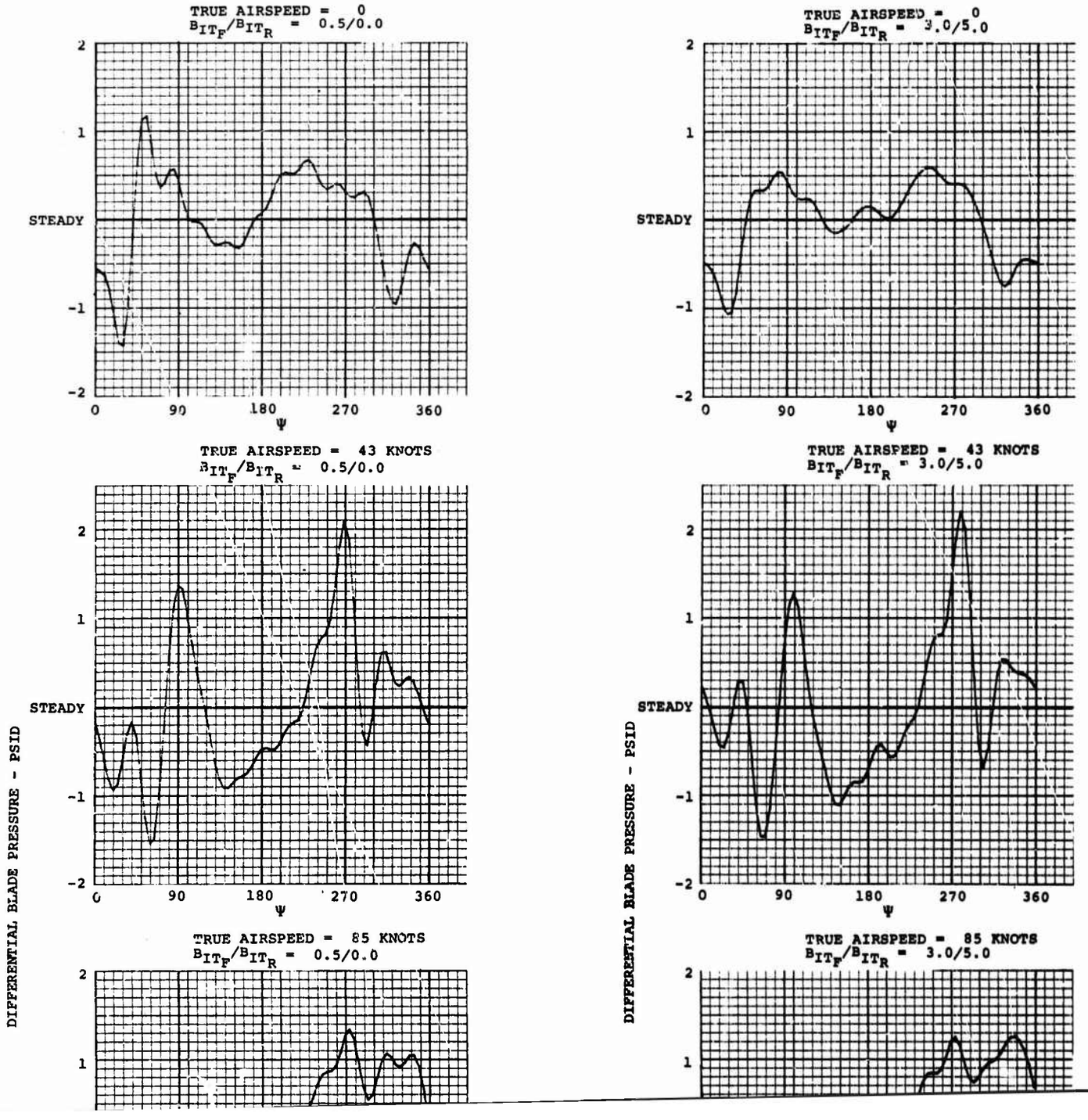
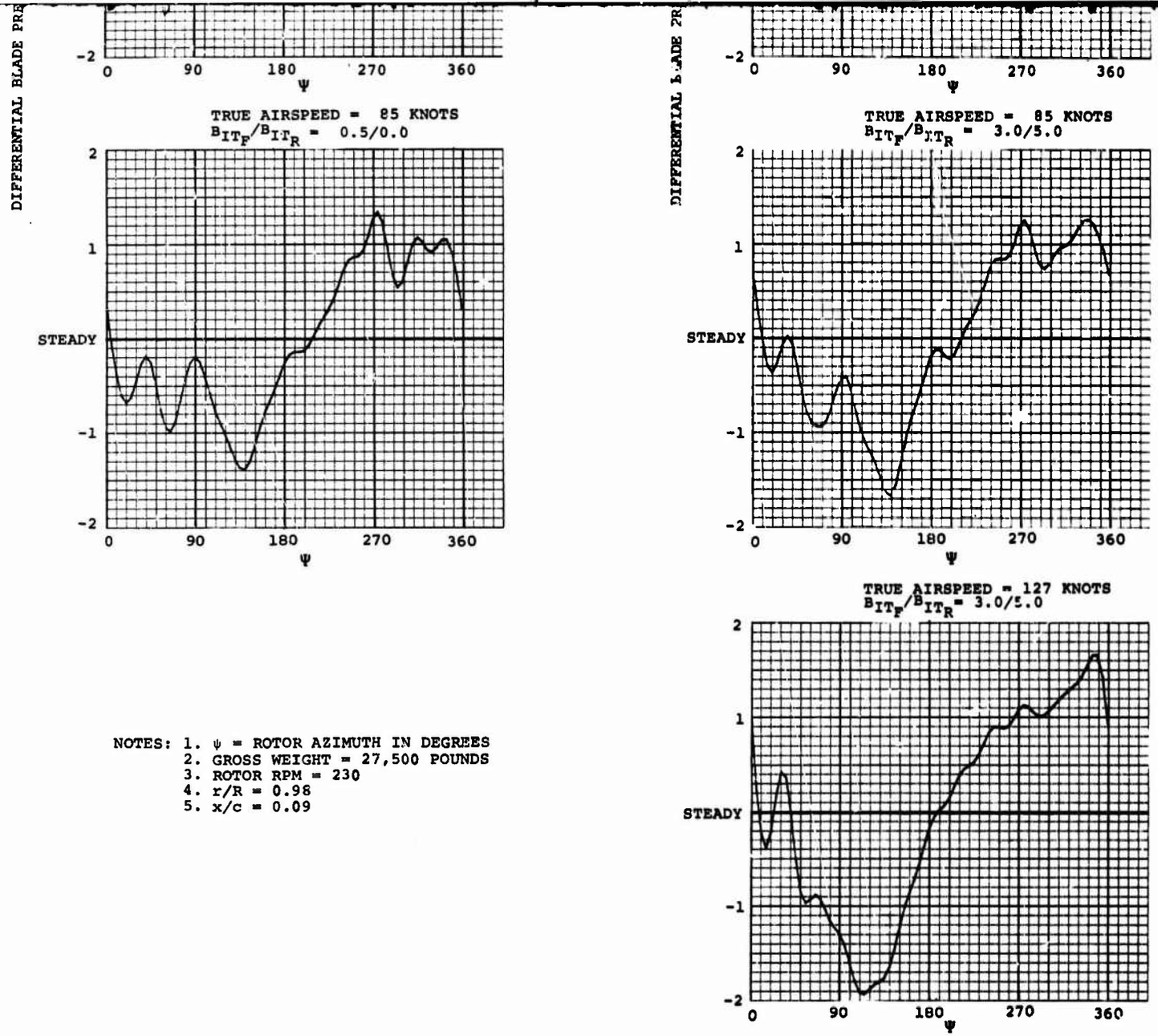



Figure 14. Chordwise Differential Pressure Distribution - Aft Rotor.

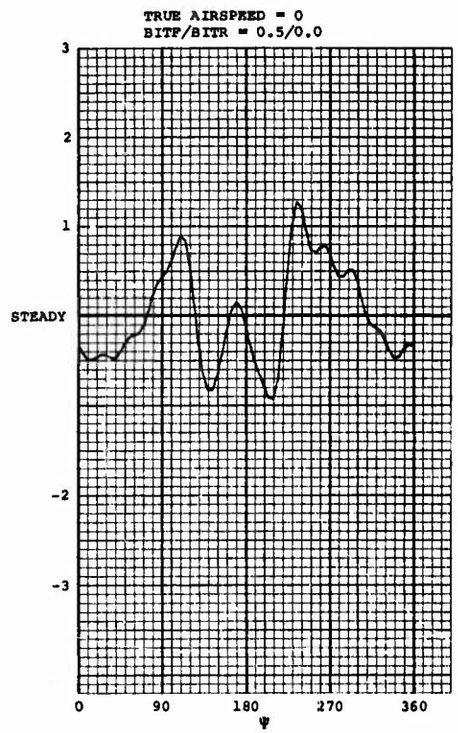

TRUE AIRSPEED = 0
$B_{IT_F}/B_{IT_R}$ = 0.5/0.0
TRUE AIRSPEED = 0
$B_{IT_F}/B_{IT_R}$ = 3.0/5.0
TRUE AIRSPEED = 43 KNOTS
$B_{IT_F}/B_{IT_R}$ = 0.5/0.0
TRUE AIRSPEED = 43 KNOTS
$B_{IT_F}/B_{IT_R}$ = 3.0/5.0
TRUE AIRSPEED = 85 KNOTS
$B_{IT_F}/B_{IT_R}$ = 0.5/0.0
TRUE AIRSPEED = 85 KNOTS
$B_{IT_F}/B_{IT_R}$ = 3.0/5.0
DIFFERENTIAL BLADE PRESSURE - PSID
STEADY
2
1
-1
-2
0
90
180
270
360
Ψ

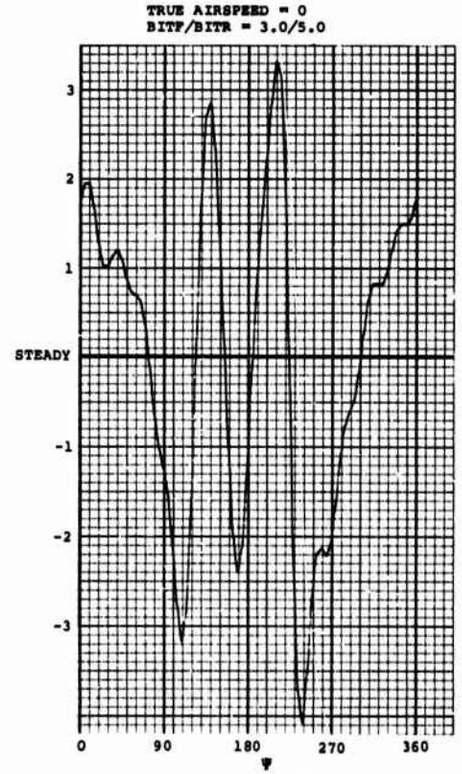


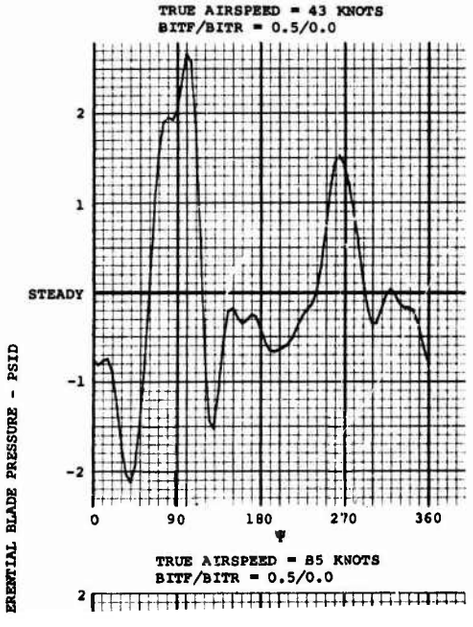

NOTES: 1. ψ = ROTOR AZIMUTH IN DEGREES
2. GROSS WEIGHT = 27,500 POUNDS
3. ROTOR RPM = 230
4. r/R = 0.98
5. x/c = 0.09

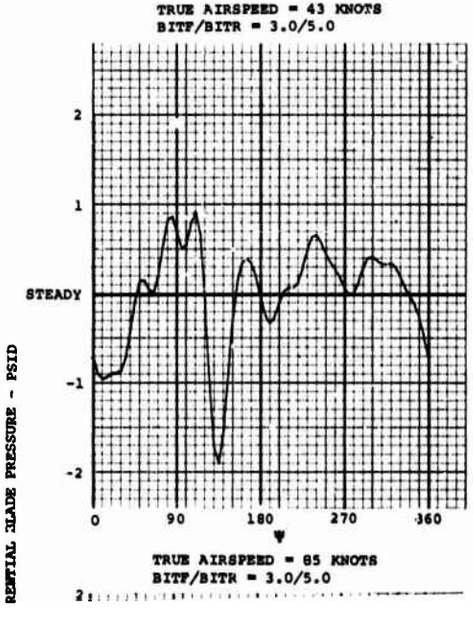
B

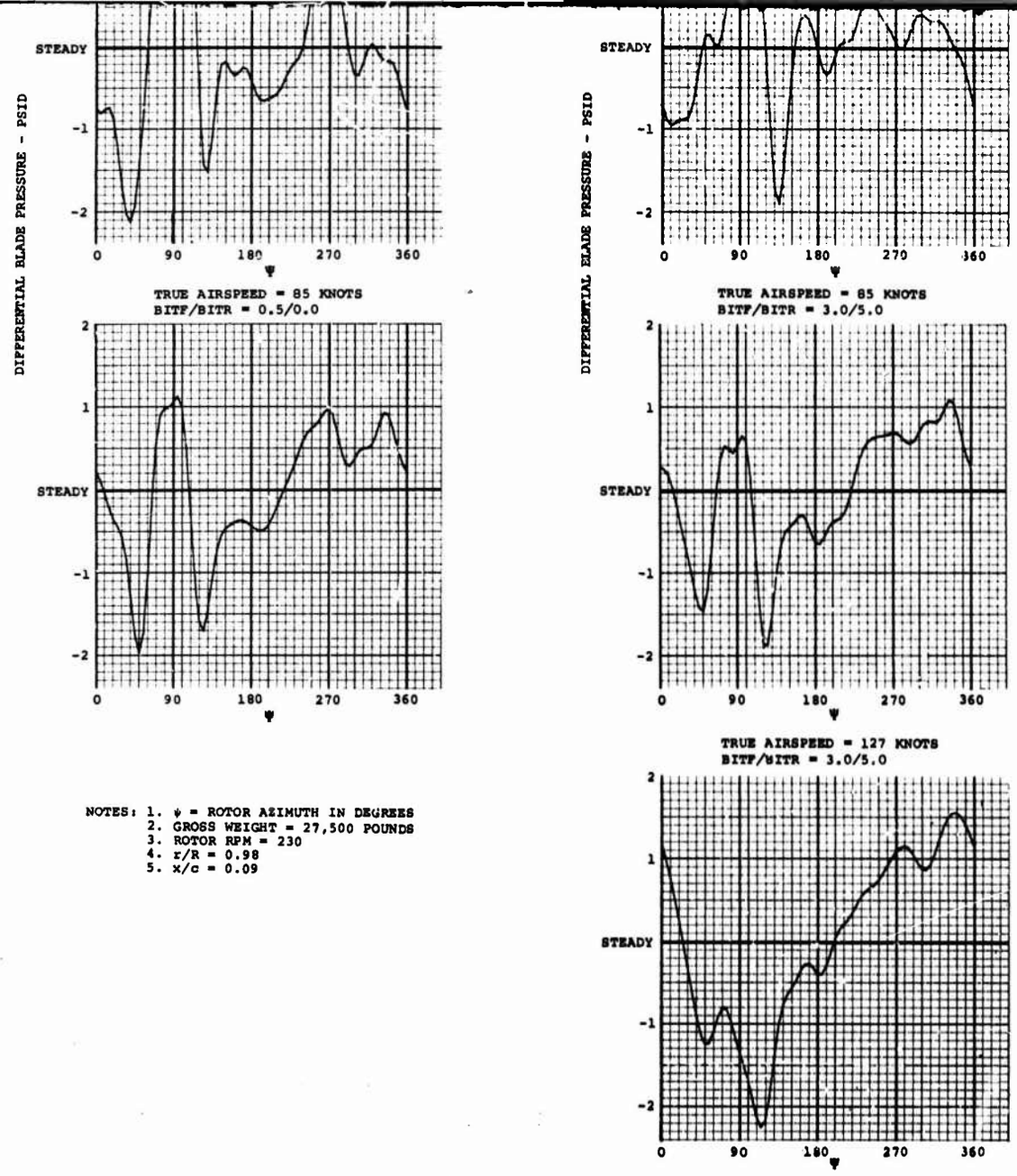
Figure 15. Differential Blade Pressure Time History - Forward Rotor (Sheet 1 of 2).


TRUE AIRSPEED = 0
BITF/BITR = 0.5/0.0
STEADY
3
2
1
-2
-3
0
90
180
270
360
Ψ


TRUE AIRSPEED = 0
BITF/BITR = 3.0/5.0
STEADY
3
2
1
-2
-3
0
90
180
270
360
Ψ


TRUE AIRSPEED = 43 KNOTS
BITF/BITR = 0.5/0.0
STEADY
2
1
-1
-2
0
90
180
270
360
Ψ
TRUE AIRSPEED = 85 KNOTS
BITF/BITR = 0.5/0.0
2
DIFFERENTIAL BLADE PRESSURE - PSID


TRUE AIRSPEED = 43 KNOTS
BITF/BITR = 3.0/5.0
STEADY
2
1
-1
-2
0
90
180
270
360
Ψ
TRUE AIRSPEED = 85 KNOTS
BITF/BITR = 3.0/5.0
2
DIFFERENTIAL BLADE PRESSURE - PSID




NOTES: 1. ψ = ROTOR AZIMUTH IN DEGREES
2. GROSS WEIGHT = 27,500 POUNDS
3. ROTOR RPM = 230
4. r/R = 0.98
5. x/c = 0.09

B

Figure 15. Differential Blade Pressure Time History - Aft Rotor (Sheet 2 of 2).

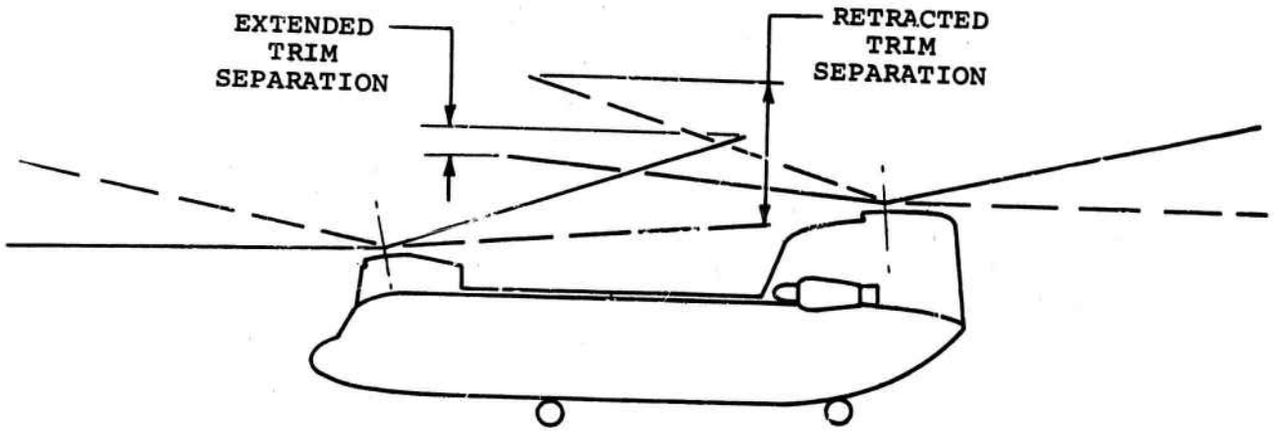



Figure 16. Effect of Cyclic Trim on Rotor Separation.

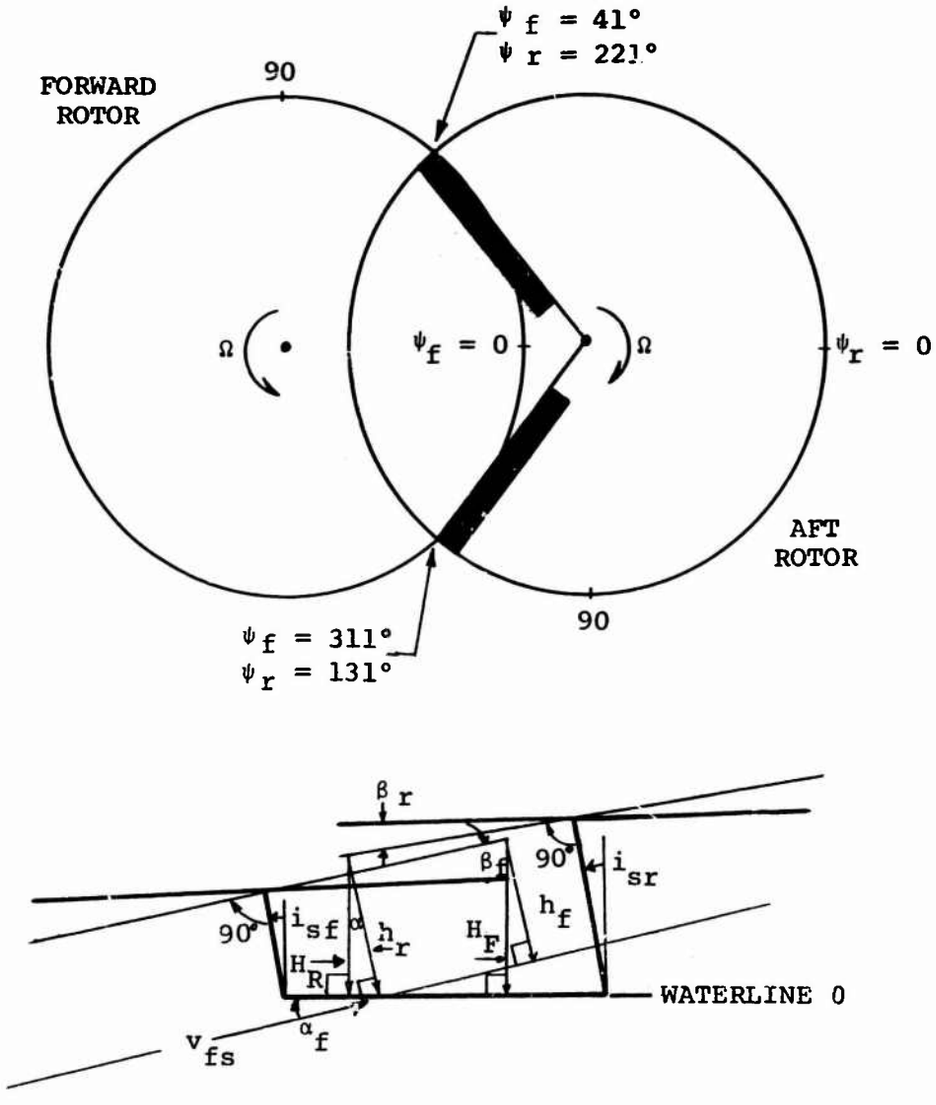



Figure 17. Geometry of CH-47A for Calculation of Blade Separation.

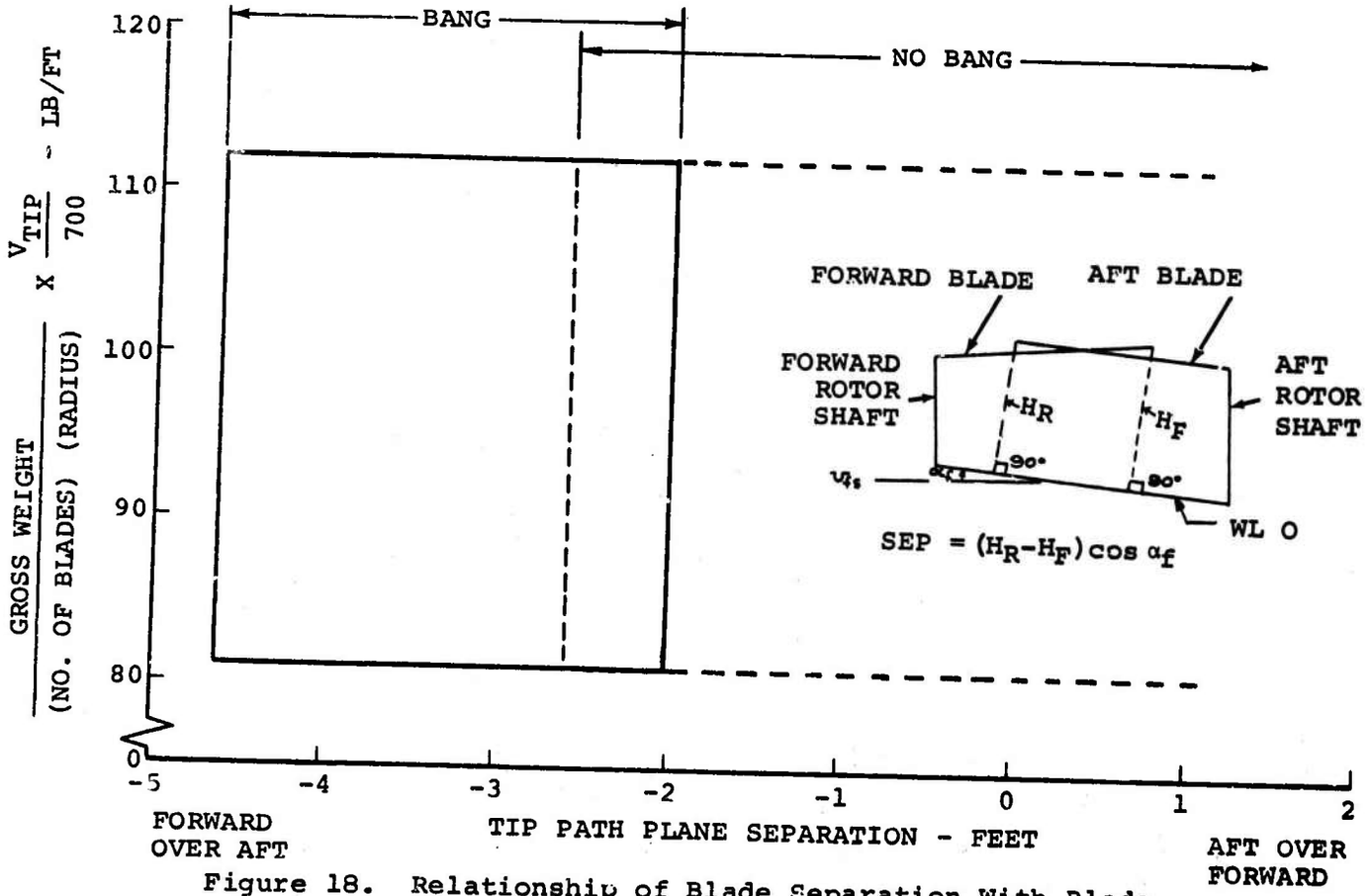



Figure 18. Relationship of Blade Separation With Blade Loading and Tip Speed.

The parameter of distance between blades, in itself, is not a cause of rotor noise, but rather an indicator. There is strong evidence that the interaction between a rotor blade and a trailed tip vortex may be the origin of the rapid pressure rises associated with blade bang. On this assumption, analyses were developed which describe the distance between blade and vortex and correlate it with rotor noise.

This method, which was developed by the Vertol Division of Boeing, is described in Appendix I. Figure 20 shows the application of this method to a slapping and nonslapping condition on the CH-47A. The banging condition, which shows calculated blade-vortex intersections, is Run 4 of Flight 395 of this program; the nonbanging case, which does not show intersection, was selected from other company data. Thus, the only significant difference between the runs was cyclic trim.

A comparison of the waveforms sensed by the microphones for a banging condition is shown in Figure 21. Also shown is an oscillograph stripout of the output of a 95-percent radius blade pressure pickup for a similar flight condition. The high-frequency cutoff of the pressure pickup precludes any direct visual comparison, since the high-frequency content (about 1600 Hz) of the microphone records is what causes the sharply spiked waveforms.

Comparison of the left-hand and right-hand airborne microphones dramatically illustrates the extremely directional characteristics of the blade bang and shows the basis of selection of the left-hand microphone as the more significant.

The difference between left-hand airborne-to-ground and between nearer and farther ground microphones simply shows the degradation in high-frequency sound experienced during propagation through the atmosphere. In each case the playback attenuation was adjusted to give a good amplitude in order to examine waveform.

Directivity of Hovering CH-47A

Although longitudinal cyclic is not normally used to trim the aircraft below airspeeds of 80 knots, it was useful for test purposes to investigate the extent to which tip path plane position would be effective in modifying rotor bang at this airspeed. It was known that a hovering aircraft trimmed to BITF/BITR = 3.0/5.0 degrees operated at a condition which produced rotor bang, and that at a longitudonal cyclic trim of BITF/BITR = 0.5/0.0 degrees, the rotor did not bang. The directional characteristics of the CH-47A are illustrated in Figure 22 for these two longitudinal cyclic trim positions. Consider first the directivity of the nonbanging rotor.

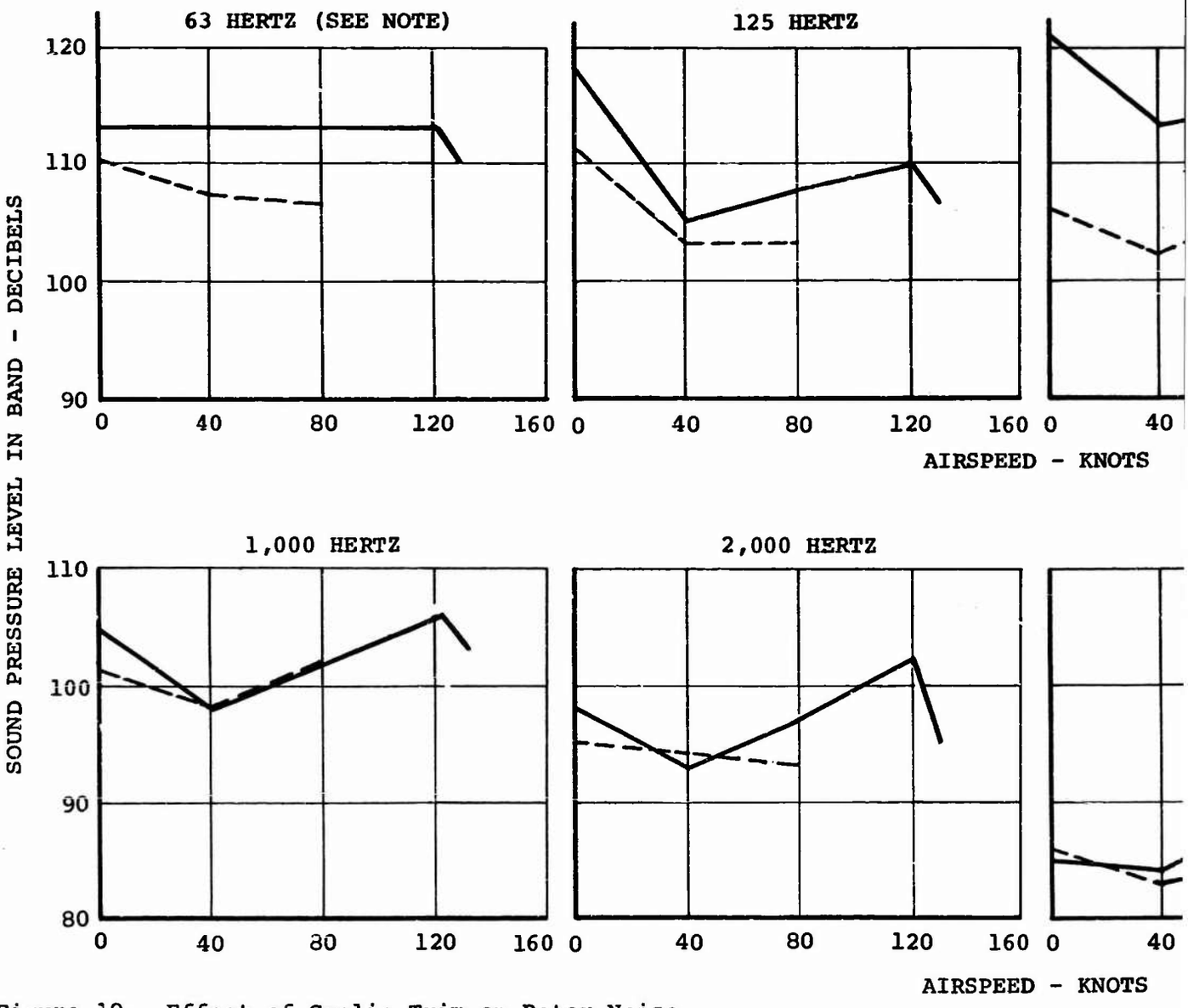
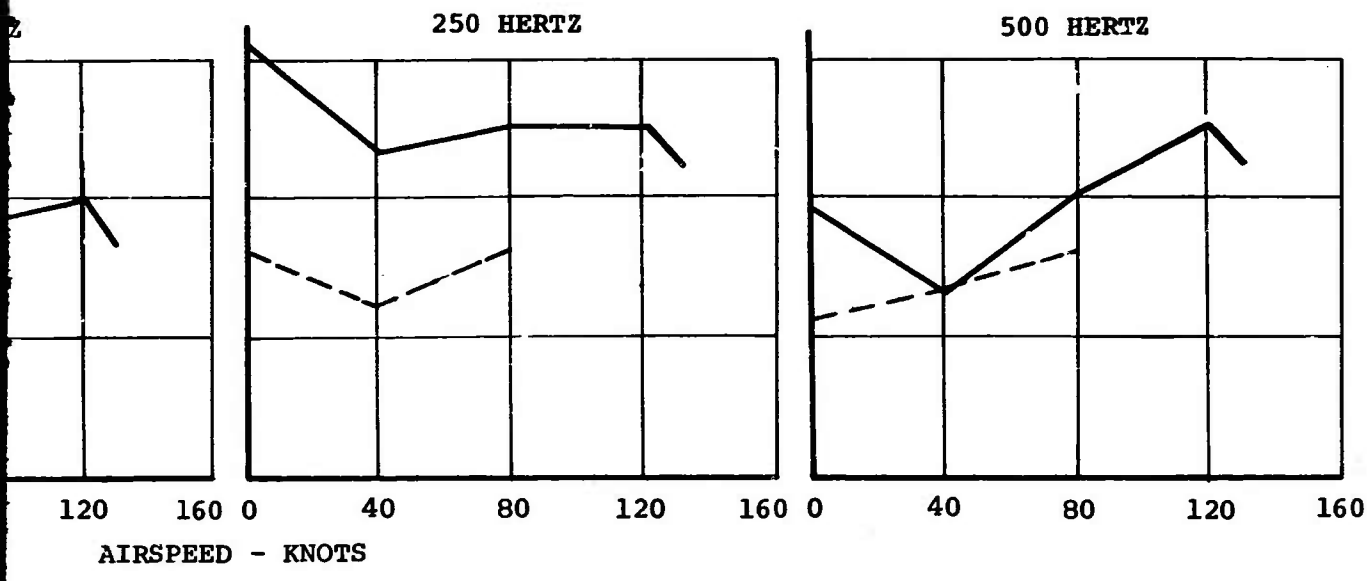
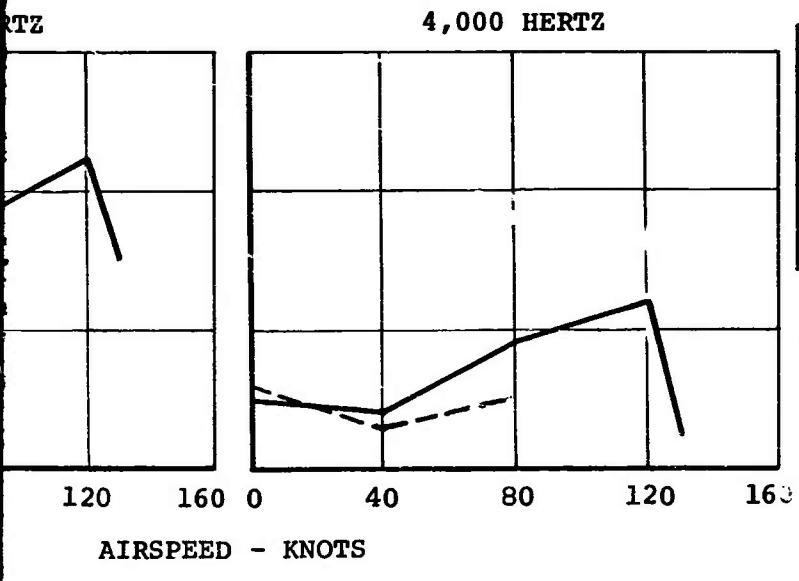



Figure 19. Effect of Cyclic Trim on Rotor Noise.




| LEGEND | | |
|---|---|---|
| LINE TYPE | TRIM | BITF/BITR |
| ——— | EXTENDED | 3.0/5.0 |
| - - - - - | RETRACTED | 0.5/0.0 |

NOTE: OCTAVE BAND CENTER FREQUENCY; GIVEN FOR EACH CURVE.

B

NOTES:
1. GROSS WEIGHT = 25,450
2. ROTOR RPM = 229
3. AIRSPEED = 98 KNOTS
4. FLIGHT NUMBER 395, RUN 4

| LEGEND | | |
|---|---|---|
| SYMBOL | BITF/BITR | CONDITION |
| --o-- | 0.5/0.0 | NONBANGING |
| —●— | 3.0/5.0 | BANGING |

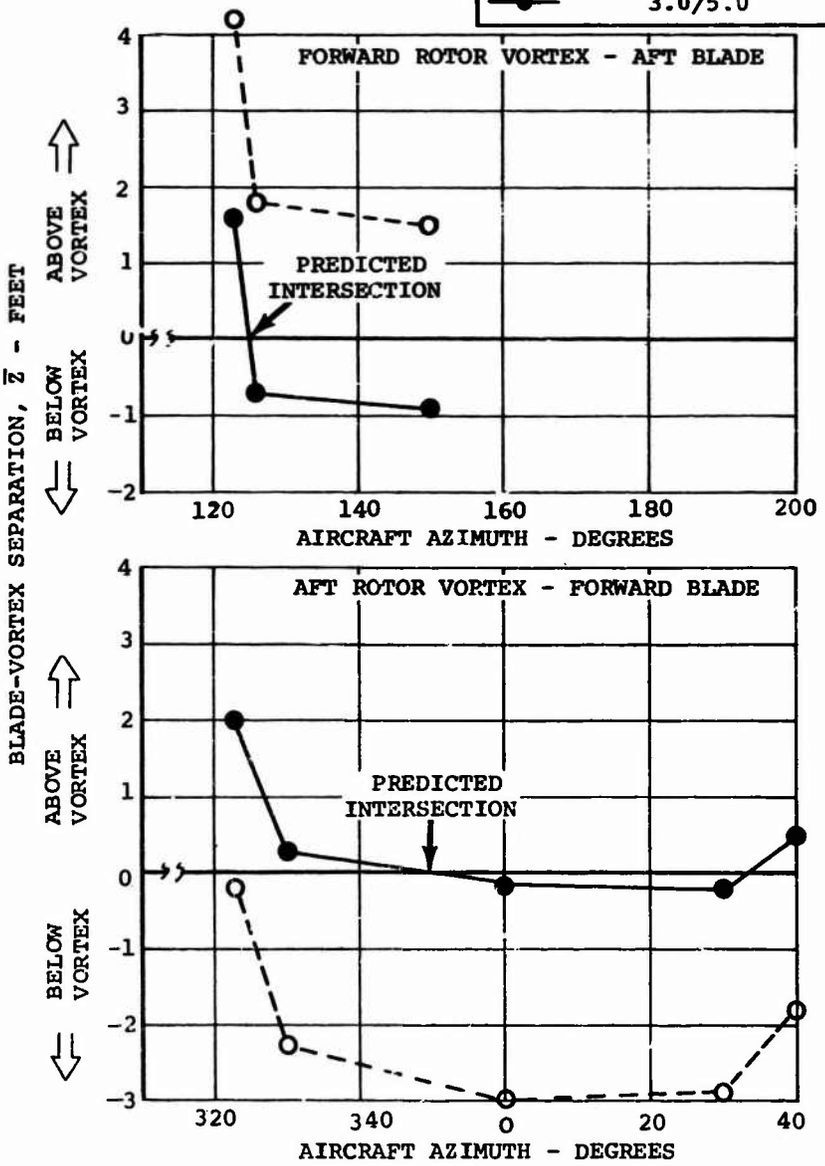



Figure 20. Predicted Blade-Vortex Separations.

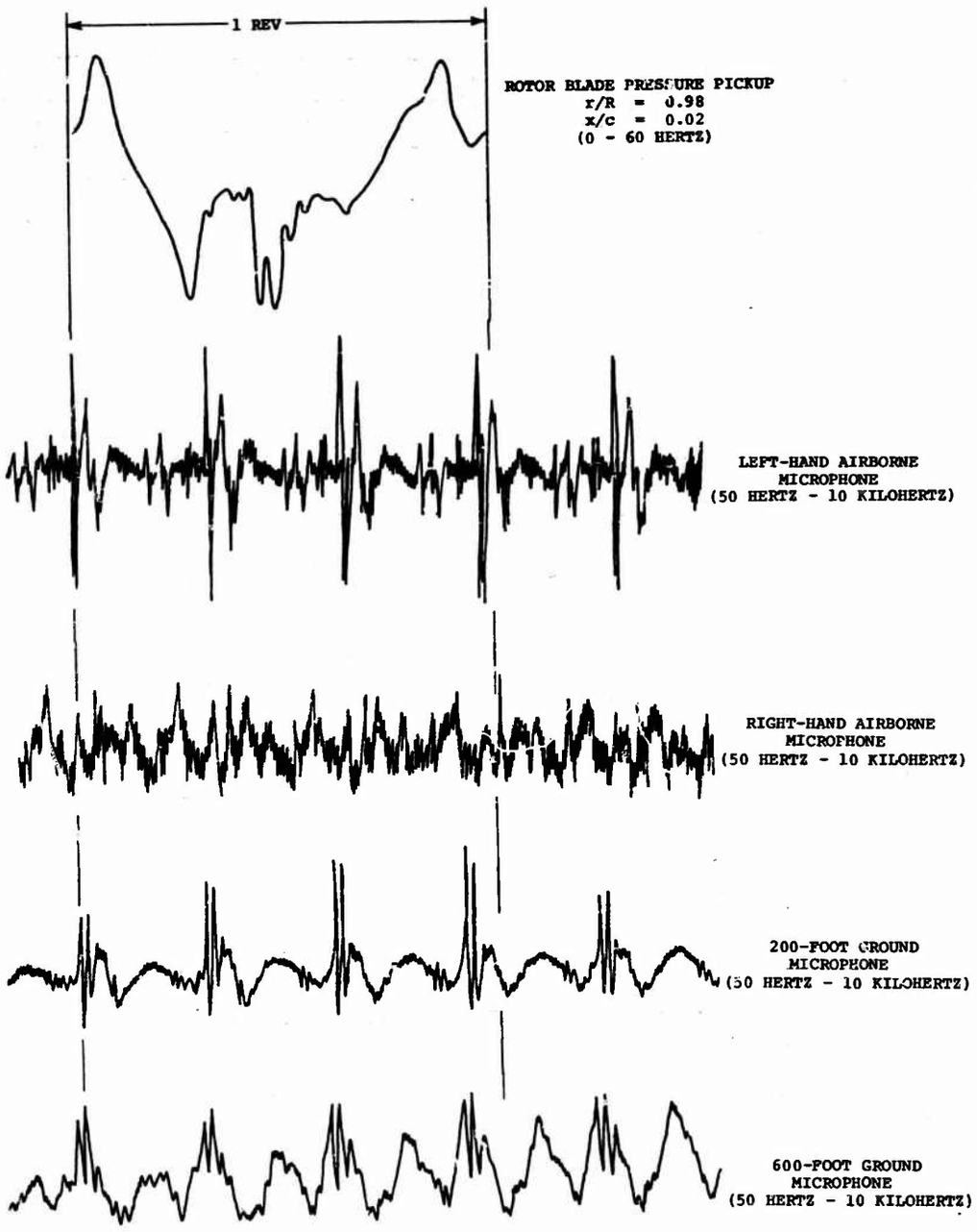



Figure 21. Comparison of Rotor Noise Waveforms.

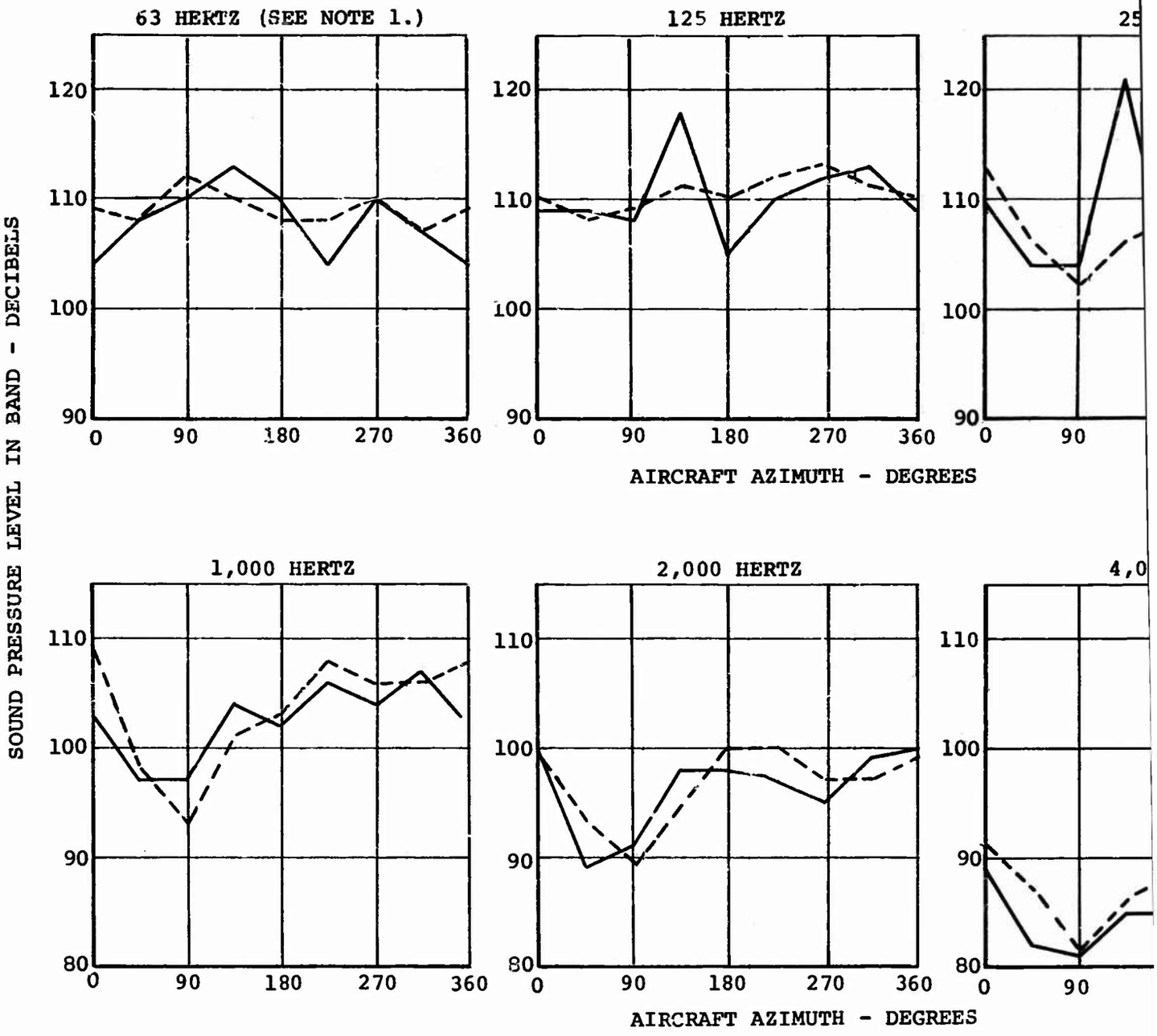
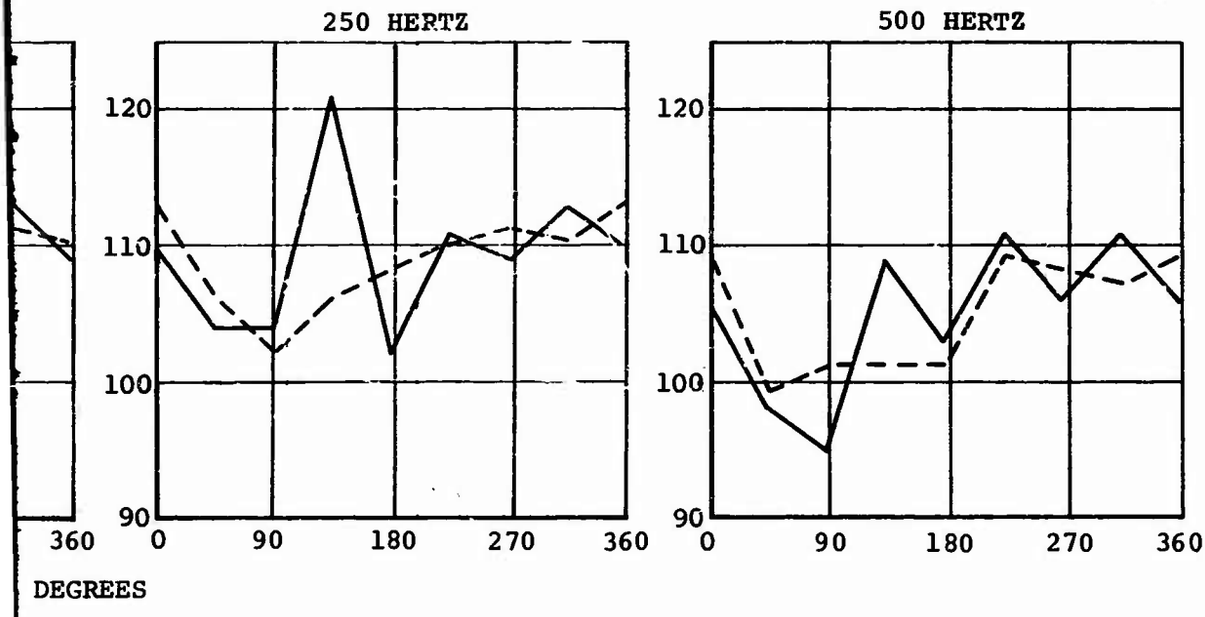
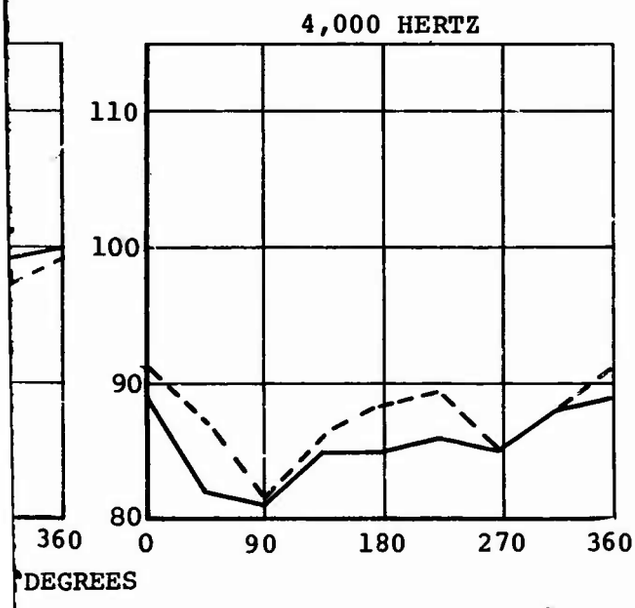



Figure 22. Directional Characteristics of Hovering CH-47A.

A




| LEGEND | | |
|---|---|---|
| LINE TYPE | BITF/BITR | CONDITION |
| ——— | 3.0/5.0 | BANGING |
| - - - - - | 0.5/0.0 | NONBANGING |

NOTES:
1. OCTAVE BAND CENTER FREQUENCY; GIVEN FOR EACH CURVE.
2. GROSS WEIGHT = 27,500 POUNDS
3. ROTOR RPM = 230
4. FLIGHT NUMBER 399

B

1

1. Retracted Trim

Although measurements were taken at both 200-foot and 600-foot radii, the trends in each case are sufficiently similar to be corroborating. For both extended and retracted trim, the discussion is based on measurements at the 200-foot radius since distance tends to exaggerate anomalies in the data. Distribution and propagation of low frequencies (63, 125 Hz) are generally constant in all directions. Beginning at 250 Hz, a trend toward lower sound pressure levels from 45 degrees to 180 degrees azimuth is observed and continues through the high-frequency end of the spectra. No verified theory currently exists to explain this distribution.

2. Extended Trim

The CH-47A in hover with extended longitudinal cyclic trim displays high noise levels (rotor bang) over its entire gross weight range. The most notable characteristic of the data with standard tips is the high noise level at the 135-degree azimuth position at 250 Hz. It is 16 to 18 db higher than the adjacent azimuth locations. This characteristic is also noted at a lower frequency (125 Hz) and a higher frequency (500 Hz).

The extremely sharp definition of azimuth corresponding to the blade bang lends further credence to the theory that blade bang arises from the interactions between rotor blades and shed tip vortices at a discrete location rather than from a source which is continuously varying around the azimuth.

Correlation With Other Parameters

No significant correlation was obtained between measured sound pressure level and the following parameters:

Gross Weight
Airspeed
Advancing Tip Speed
Sideslip Angle

This is probably due to a combination of low sensitivity of noise to these parameters over the range of variation obtainable on the aircraft, and to the overpowering effect of blade-vortex intersections, which, when they occur, mask effects which might otherwise be observable.

It was also found that no significant correlation could be established between sound pressure level and the following:

Pitch Link Load (Forward and Aft)
Cockpit Vibration (Vertical and Lateral)
Cabin Vibration (Vertical and Lateral)

In this case, the indication is that the causes of these phenomena and the rotor noise are mutually independent.

## EVALUATION OF THE POROUS TIP - PHASE II

### Rotor Noise - Hover

In hover, the porous tip proved to be extremely effective in reducing the intensity of rotor slap when it occurred. From the 200-foot microphone data, this is clearly shown in Figure 23 at the critical azimuth of 135 degrees. With a retracted trim (Figure 24), the effect is less pronounced since vortex interaction effects play a less important role.

It is notable that no azimuth position for any hovering test point displayed more than a moderate rotor slap with the porous tip. However, the porous tip did display somewhat higher sound levels above 2,000 Hz than the standard tip. This may be due to the cylindrical ports in the tip which are open-ended pipes of wavelength $\lambda = 2L$.

For the CH-47A rotor blade which has a chord of 1.92 feet and an NACA 0012 section, the maximum port length is

$$L_{max} = c \cdot t/c = 1.92(0.12) = 0.23 \text{ ft}$$

where t/c is blade thickness ratio.

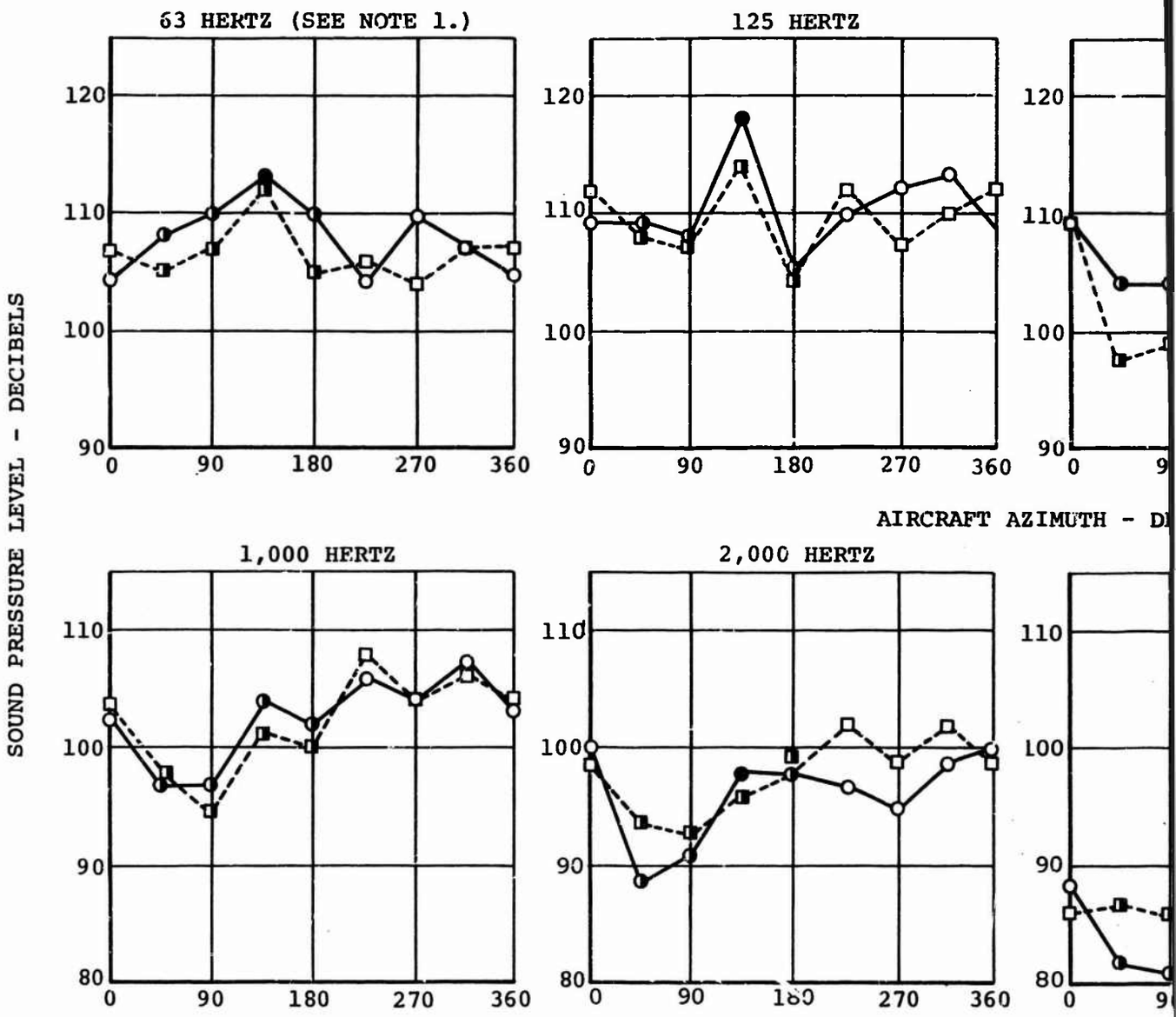
The corresponding wavelength of a resonant port is

$$\lambda = 2L = 2(0.23) = 0.46 \text{ ft}$$

with a frequency of

$$f = \frac{C}{\lambda} = \frac{1,125}{0.46} = 2,450 \text{ Hz.}$$

Frequencies associated with other port lengths in the tip range up to 9,750 Hz for the shortest wavelength, and the illustrations for the porous tip hovering cases reflect this increase in sound level at 2 kHz and 4 kHz. In general, the porous tips tend to have lower sound pressure amplitudes in the low frequencies than the standard tips (see Figure 25). It was noted that when the local flow over the tip was normal to the axis of the port, as in flat pitch during ground idle conditions, excitation of standing waves in the tubular ports was particularly noticeable. When the blade angle of attack was increased to that required for hovering, these standing waves were virtually eliminated. A comparison of noise levels during flat pitch and hover is shown in Figure 25.

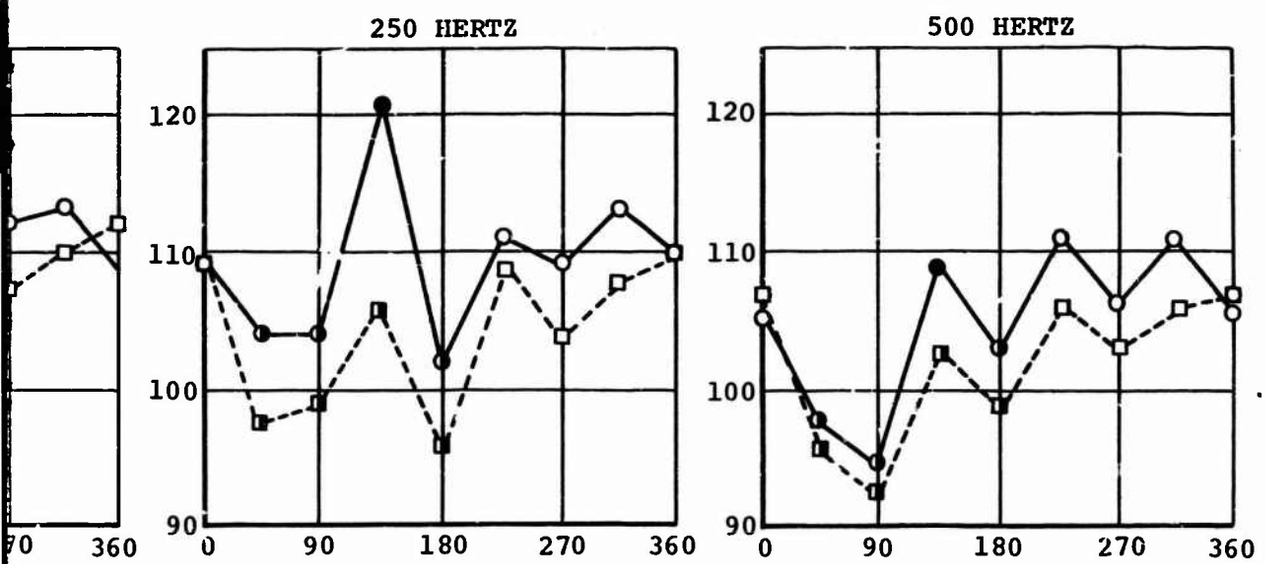



NOTES:
1. OCTAVE BAND CENTER FREQUENCY; GIVEN FOR EACH CURVE.
2. GROSS WEIGHT = 27,500 POUNDS
3. ROTOR RPM = 230
4. MICROPHONE 200 FEET FROM AIRCRAFT

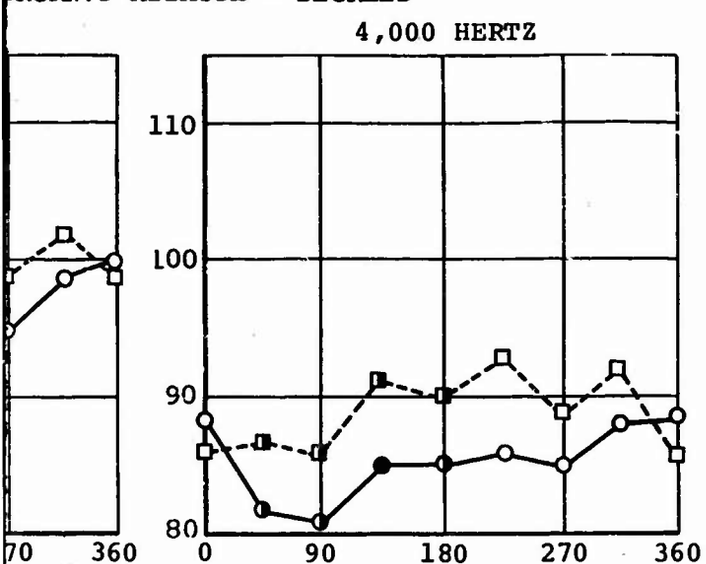
Figure 23. Comparison of Standard and Porous Tips in Hover - Extended Trim.

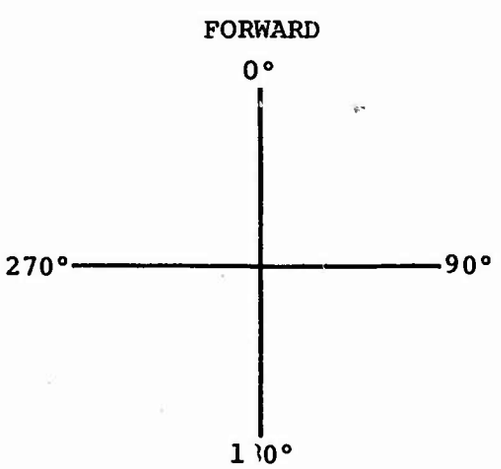


A




IRCRAFT AZIMUTH - DEGREES



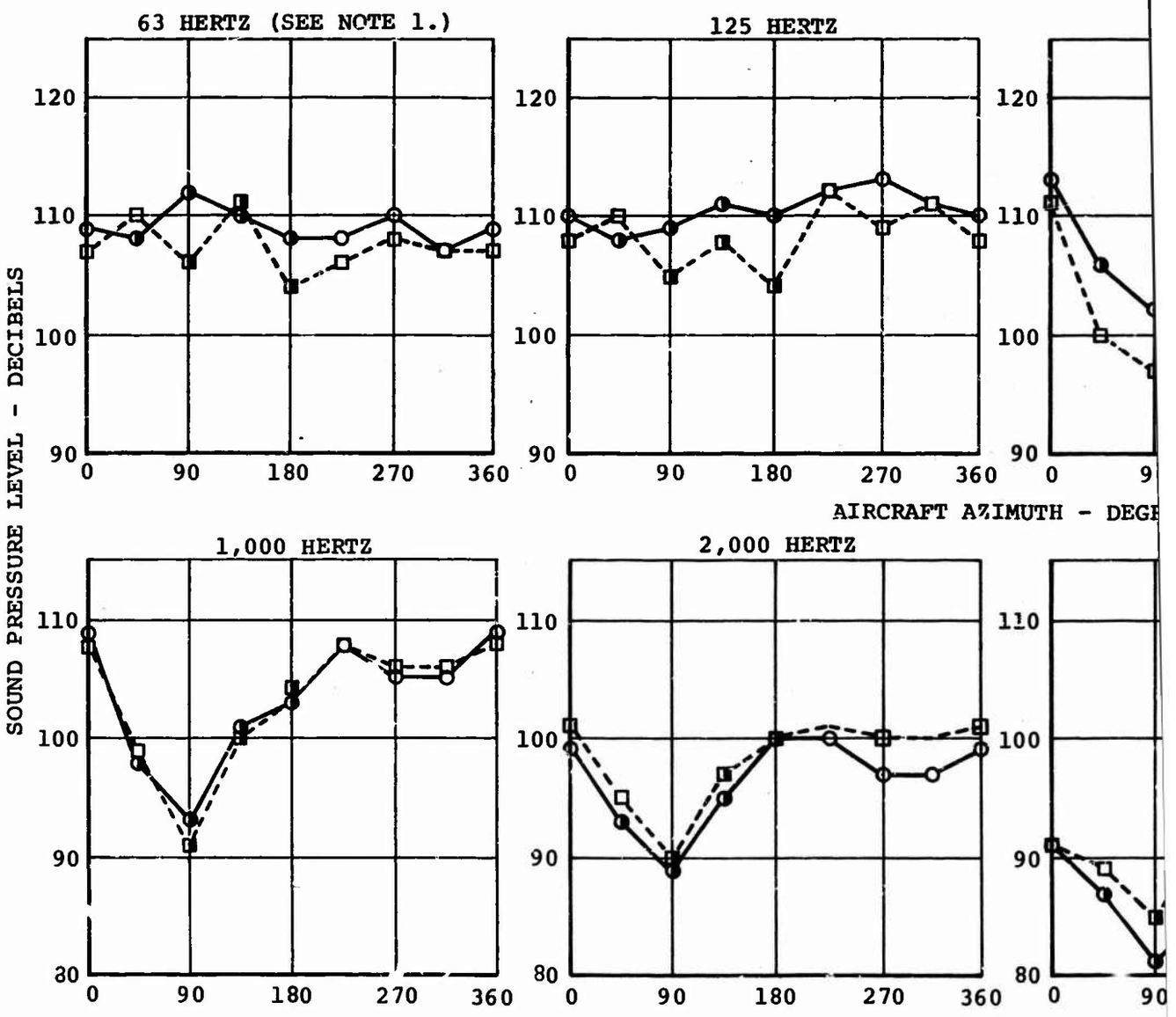




VIEW LOOKING DOWN

IRCRAFT AZIMUTH - DEGREES

| LEGEND | | | |
|---|---|---|---|
| SYMBOL | SUBJECTIVE RATING | LINE TYPE | TIP CONFIGURATION |
| ○ □ | NONBANGING | ——— | STANDARD |
| ● ■ | HEAVY BANGING | - - - - - | POROUS |
| ◑ ◧ | INTERMEDIATE BANGING | | |

B

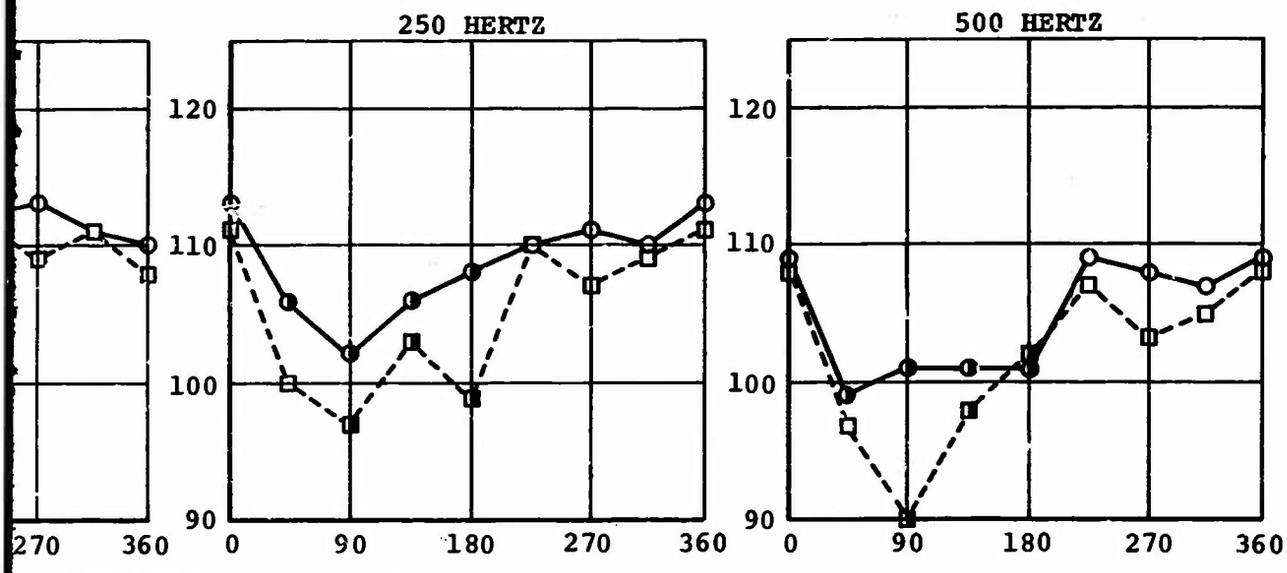


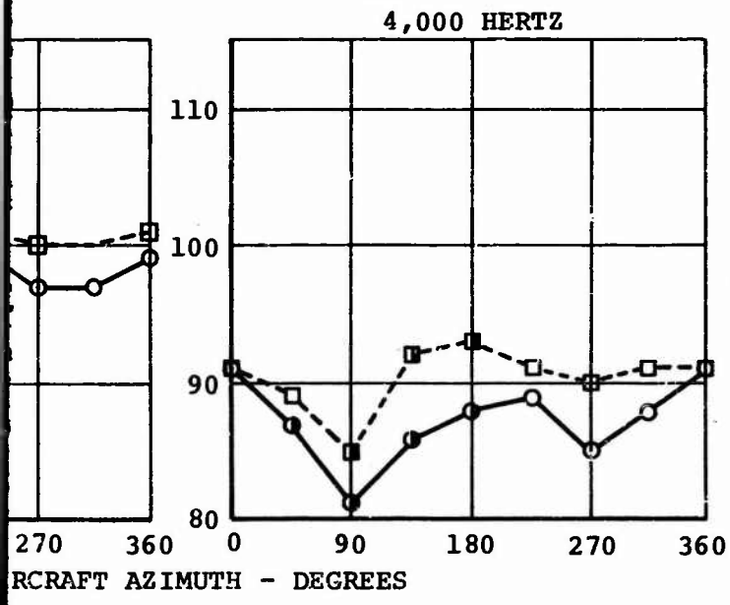

NOTES:
1. OCTAVE BAND CENTER FREQUENCY; GIVEN FOR EACH CURVE.
2. GROSS WEIGHT = 27,500 POUNDS
3. ROTOR RPM = 230
4. MICROPHONE 200 FEET FROM AIRCRAFT

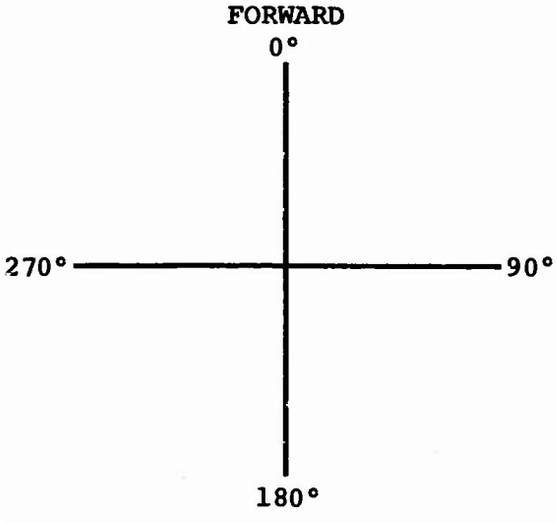
Figure 24. Comparison of Standard and Porous Tips in Hover - Retracted Trim.



A




VIEW LOOKING DOWN

| LEGEND | | | |
|---|---|---|---|
| SYMBOL | SUBJECTIVE RATING | LINE TYPE | TIP CONFIGURATION |
| ○ □ | NONBANGING | ——— | STANDARD |
| ● ■ | HEAVY BANGING | - - - - - | POROUS |
| ◑ ◨ | INTERMEDIATE BANGING | | |

B

1

| LEGEND | | | |
|---|---|---|---|
| LINE TYPE | CONDITION | ROTOR RPM | WEIGHT (LB) |
| ——— | STANDARD TIP, HOVER | 230 | 27,850 |
| ·-·-·-·- | POROUS TIP, HOVER | 230 | 28,200 |
| – – – – | POROUS TIP, FLAT PITCH | 180 | 27,500 |

NOTE:
MICROPHONE 200 FEET FROM AIRCRAFT AT 90° AZIMUTH (FLAT-PITCH DATA AVAILABLE ONLY AT 90° AZIMUTH)

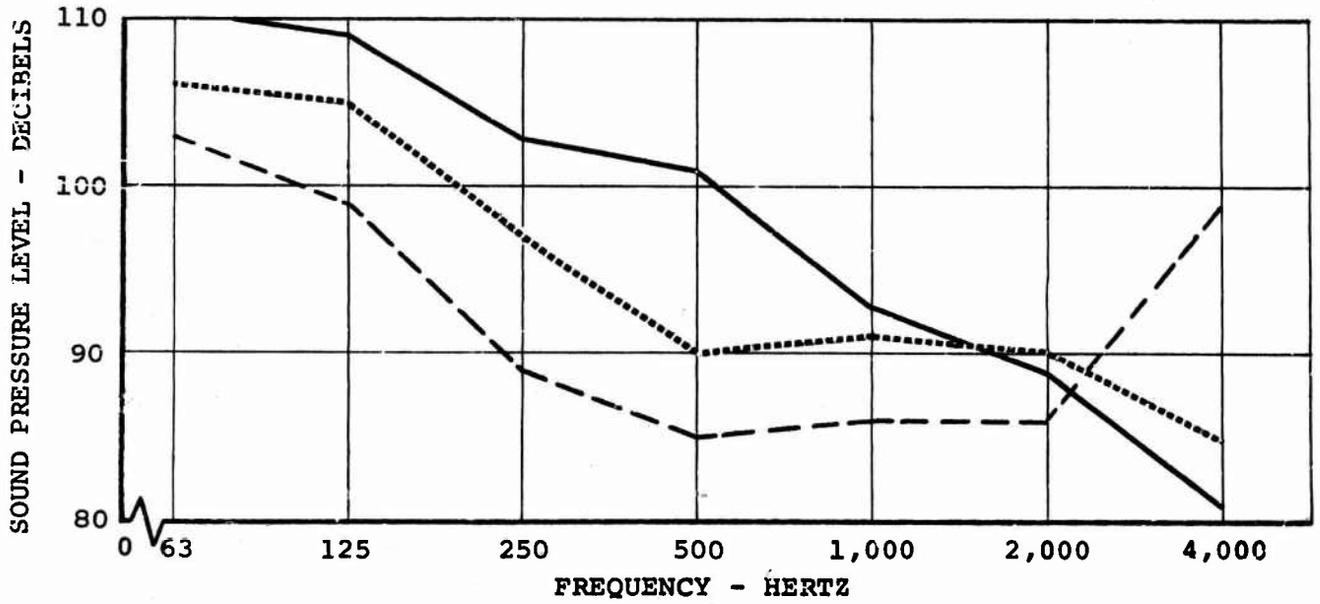



Figure 25. Comparison of Porous Tip Noise During Flat Pitch and Hover.

## Rotor Noise - Forward Flight

The far field forward flight data are shown in Figure 26. An appreciable reduction in sound pressure level with the porous tips was achieved at 80 knots but is not evident at other airspeeds. Detailed examination of the data confirmed the validity of the values shown but failed to indicate any verifiable explanation.

Flight with standard blades demonstrated that rotor-bang levels are established by blade-to-vortex separation: when intersections occurred, blade pressures (Figure 15) and noise levels (Figure 19) were higher. It is reasonable to assume that blade/vortex intersections also occurred during hover with the porous tips; however, for the reasons given on page 4, no blade pressures were measured to confirm this. Thus, the reduction in noise level measured with the porous tip (Figure 25) must result from a modification in the vortex trailed by the blade with the porous tip.

Measurements of the vortex diameter in the wake of a full-scale helicopter rotor would have conclusively demonstrated this modification, but this was not within the scope of this program and would be the subject of a separate investigation. The increased size of the vortex core with its associated reduction in induced velocity, while sufficient to produce significant noise reductions for the hovering aircraft, was generally insufficient for forward speeds even as low as 40 knots.

## Subjective Effects of the Porous Tip

Oscillographic records of hover noise level for the standard and porous tip were stripped out through a C-network filter. The comparisons are illustrated in Figure 27.

The large amplitude of the pulse at blade-passage frequency, which is characteristic of the standard tip, is considerably reduced with the porous tip; and the rise time is significantly increased, indicating a reduction in the sharpness of the noise. This characteristic is not evident from the sound pressure data above; for this reason, all the data in the subject program have been subjectively rated for comparison purposes only. This information is shown in Appendix V.

It is noteworthy that observers described the flyby noise with the porous tip as having a more "hollow" sound than the standard tip flyby, a characteristic evidently arising from modifications in the trailed vorticity.

| LEGEND | | | |
|---|---|---|---|
| LINE TYPE | CONDITION | ROTOR RPM | WEIGHT (LB) |
| ——— | STANDARD TIP, HOVER | 230 | 27,850 |
| -------- | POROUS TIP, HOVER | 230 | 28,200 |
| – – – – | POROUS TIP, FLAT PITCH | 180 | 27,500 |

NOTE:
MICROPHONE 200 FEET FROM AIRCRAFT AT 90° AZIMUTH (FLAT-PITCH DATA AVAILABLE ONLY AT 90° AZIMUTH)

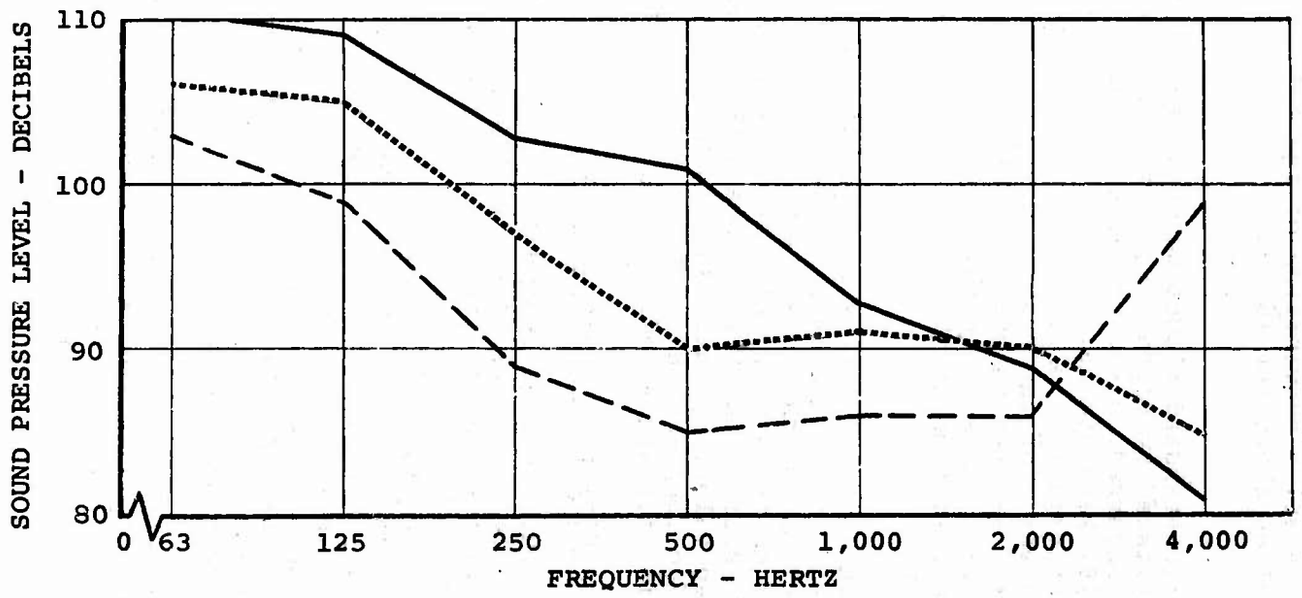



Figure 25. Comparison of Porous Tip Noise During Flat Pitch and Hover.

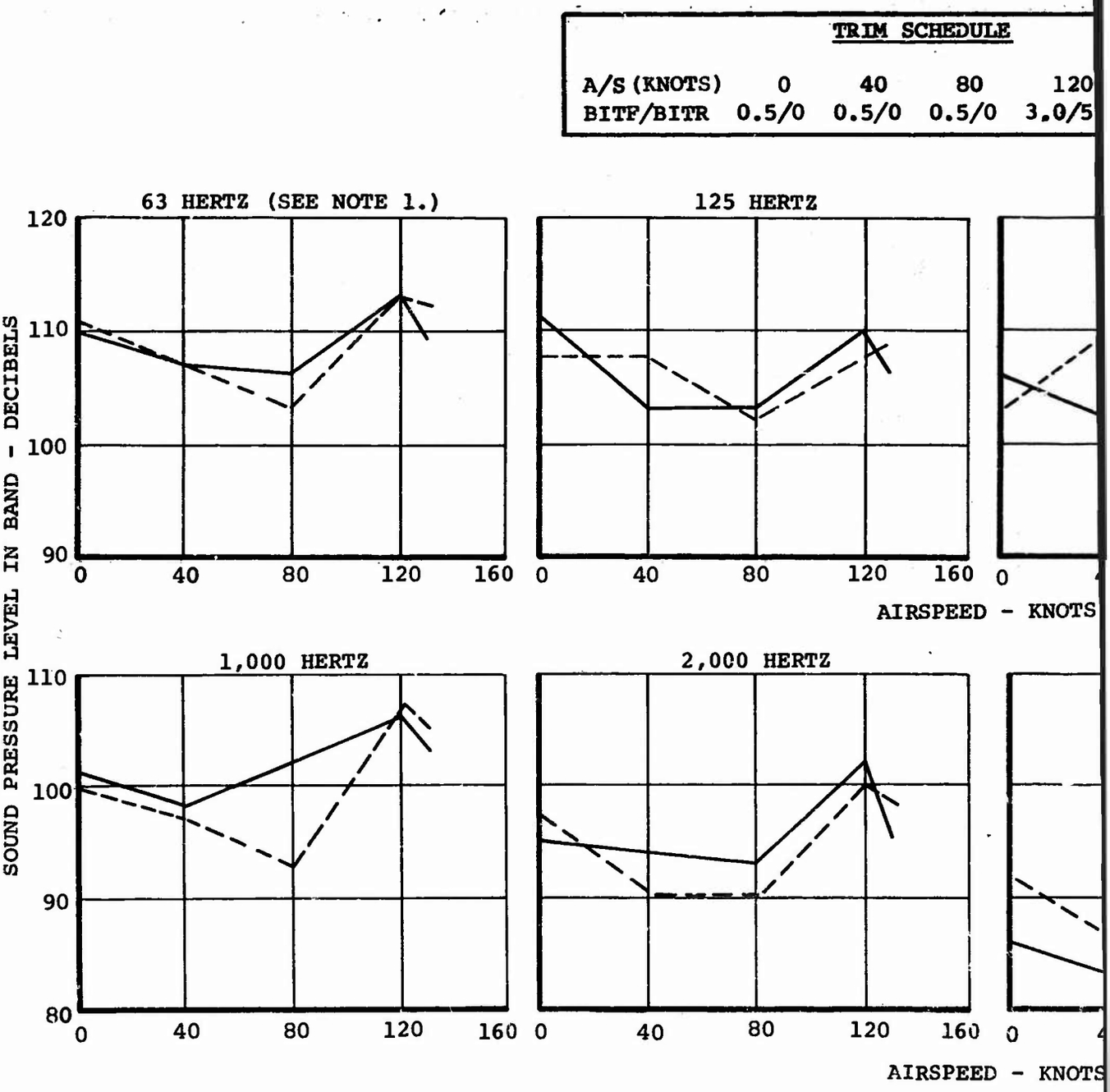
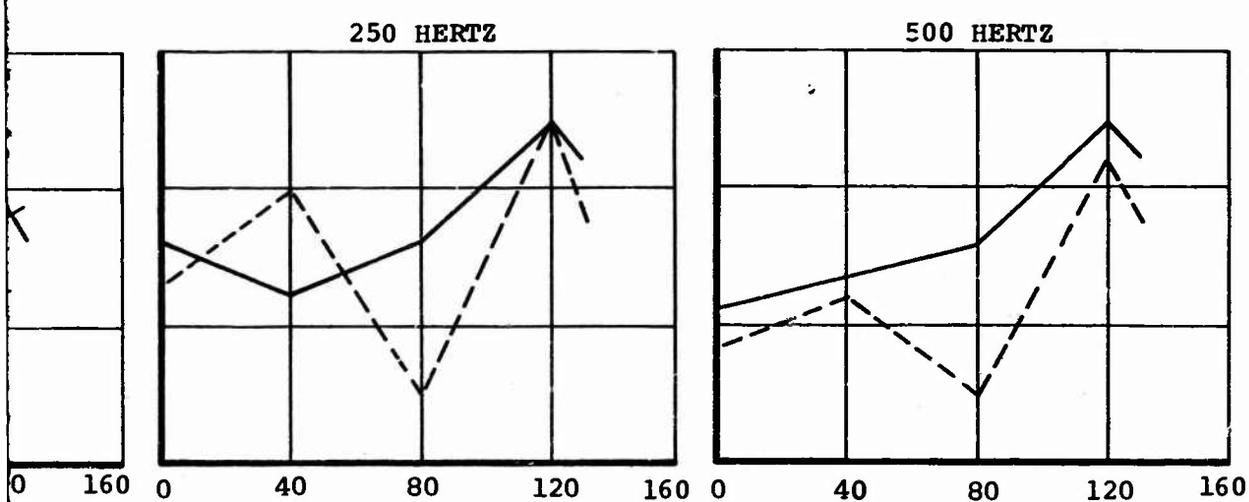


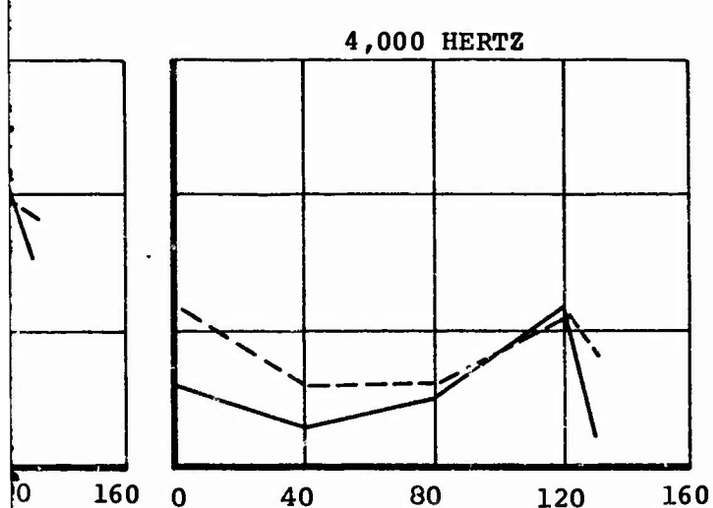

Figure 26. Comparison of Standard and Porous Tip Fly-By Noise - Scheduled Trim.



A

| M SCHEDULE | | | |
|---|---|---|---|
| 0 | 80 | 120 | 130 |
| /0 | 0.5/0 | 3.0/5.0 | 3.0/5.0 |




| LEGEND | |
|---|---|
| LINE TYPE | TIP CONFIGURATION |
| ——— | STANDARD |
| - - - - - | POROUS |

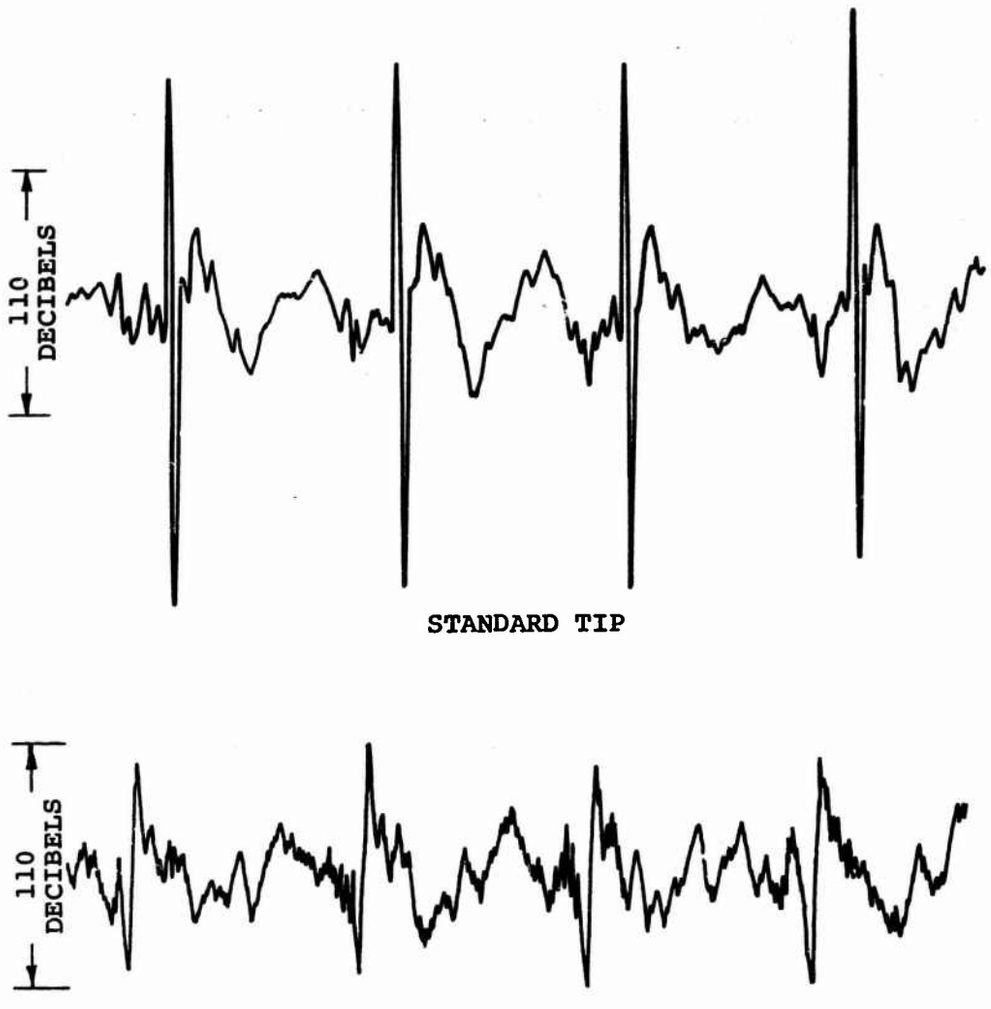
NOTES:

1. OCTAVE BAND CENTER FREQUENCY; GIVEN FOR EACH CURVE.
2. GROSS WEIGHT = 27,500 POUNDS
3. ROTOR RPM = 230
4. DATA IS MAXIMUM VALUE FOR EACH AIRSPEED, AS FOLLOWS:

   HOVER - 135 DEG AZIMUTH

   FORWARD FLIGHT - MAXIMUM VALUE MEASURED ON SIDELINE MICROPHONE DURING FLYBY

B




NOTES:
1. GROSS WEIGHT = 27,500 POUNDS
2. ROTOR RPM = 230
3. BITF/BITR = 3.0/5.0
4. MICROPHONE 200 FEET FROM AIRCRAFT AT 135° AZIMUTH

Figure 27. Comparison of Standard and Porous Tip Time History - Hover.

## Power Required

It was recognized that the drag due to the porosity of the blade tip would require significant increases in helicopter power required over the airspeed envelope. Based on preliminary wind tunnel measurements, the increment required for the porous tips was estimated (Reference 4) to be 120 horsepower in hover for a CH-47A helicopter, but measured rotor shaft torque values converted to horsepower indicate that increases of about 600 horsepower were actually required. This is shown in Figure 28 for all airspeeds. At 130-knot airspeed, the power-required curves for the porous and standard tip converge. The increase in power required for the porous tip does not limit the CH-47A from a power-available standpoint, however, and the aircraft was able to achieve 130 knots at the test gross weight. Noise levels at the high forward speeds are similar for both the standard and porous tips. It appears that, above 135 knots, the porous tip might require less power than the standard tip.

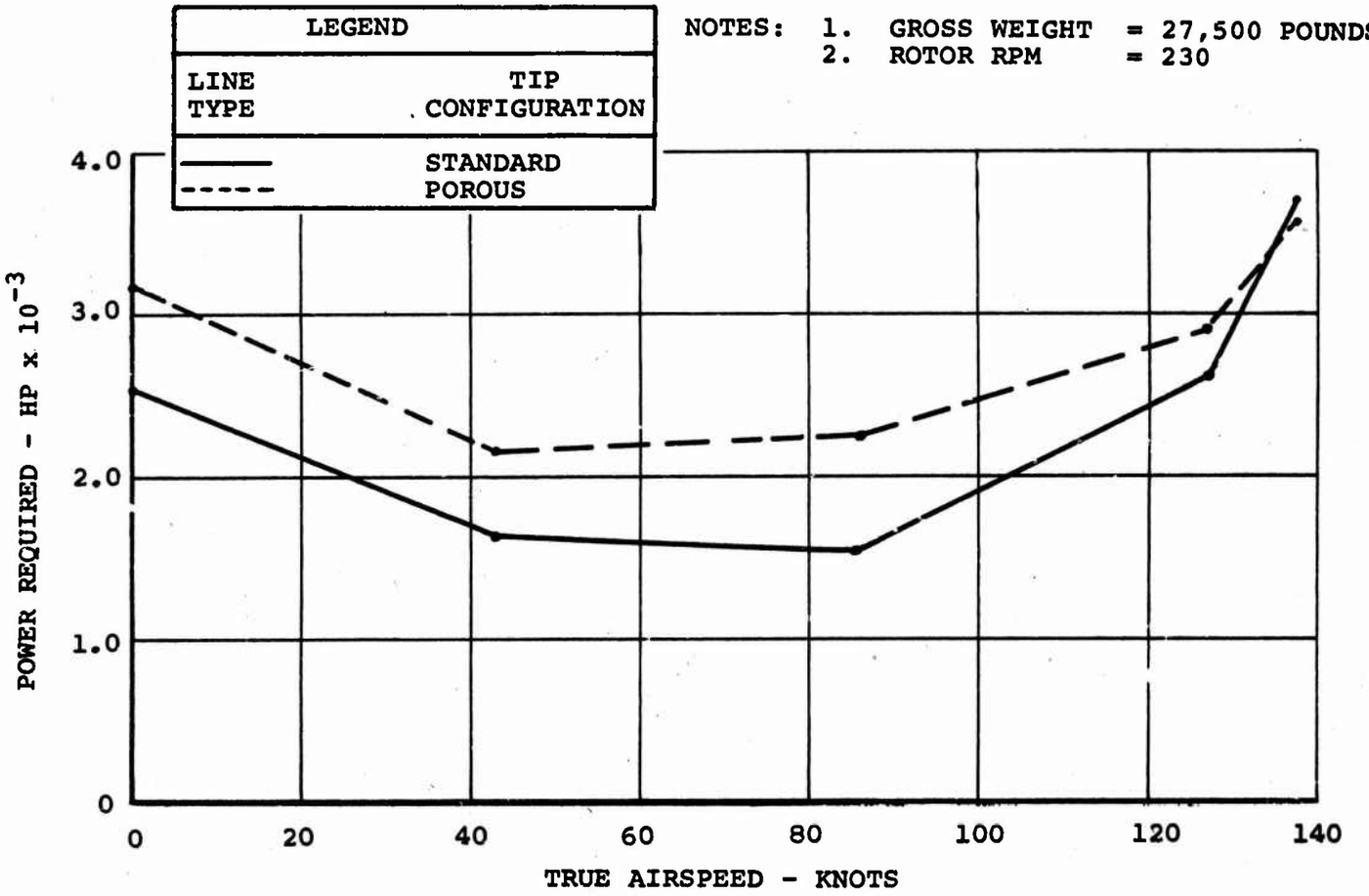



Figure 28. Comparison of Blade Tip on Power Required at Various Airspeeds.

## CONCLUSIONS AND RECOMMENDATIONS

The experimental investigation which comprised Phase I of this program and which resulted in a detailed correlation study of rotor noise with other variables and parameters revealed that, in essence, one critical factor exists in the generation of rotor noise on the CH-47A helicopter. This factor is the intersection of a rotor blade with the rolled-up tip vortex shed from another on the opposite rotor. When an intersection occurs, particularly over the outer sections, the rotor noise may be as much as 10 to 15 db higher (at specific frequencies) than when these intersections do not take place. The effects of all other variables which were considered in the subject program are nearly an order of magnitude lower in importance. In a program of this extent, where large numbers of data points are gathered over relatively long periods of time, particularly in terms of many weeks (flight 393 occurred on 4/5/66, flight 400 on 5/2/66), variations in a specific parameter can be difficult to control. This in no way implies that any of the data is insignificant, but rather bolsters the fact that the important variable, blade-vortex separation, was notable throughout the program, whereas many of the secondary parameters appeared to have some inconsistent effects. It is nevertheless apparent that control of rotor noise on a tandem rotor helicopter is strongly dependent on blade-vortex intersections.

The modification of the trailed vorticity with the porous tip was measured only in terms of the noise produced when intercepted by a rotor blade. In hover, this amounted to a reduction of 15 db at 250 Hz. It is noteworthy also that the blade noise during hover with the porous tip never displayed more than a moderate amount of banging at any location. In forward flight the porous tip did not show a consistent effect on rotor noise although at 80 knots a 10-db reduction was achieved.

When blade banging occurs, any effects which materialize from the mechanism of generation are apparently localized in the rotating system of the rotors and are not transmitted to the control system or airframe, since none of the measured parameters, with the exception of rotor blade pressures, showed a substantial correlation with noise.

Based on the premise that blade bang results from a blade-vortex intersection, further study should be made to determine more precisely how these intersections may be avoided in all flight regimes. This study might well be one of vortex visualization on full-scale aircraft or a wind tunnel model combined with a comparison with up-to-date theory to permit an accurate prediction technique for the trailed vorticity. With this technique available to the designer, the major external noise source of the tandem rotor helicopter undoubtedly could be eliminated.

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## APPENDIX I

## CALCULATION OF BLADE-VORTEX INTERSECTIONS

### X-Y PLANE

The locus of possible blade-vortex filament intersections and intersecting blade element radial positions in the two-dimensional X-Y plane are determined graphically for both hover and forward flight conditions. The appropriate rotor advance ratios ($\mu$) with respect to the rotor disc plane were used in the forward flight cases. Because of the insignificant error involved, the blade flapping was ignored in the X-Y plane representation.

1. Hover - In hover, the possible blade-vortex intersection occurs in the rotor overlap area. Emphasis was applied to the segments of the overlap area where the blade element experiencing the intersection has an outboard radial location of from 48 to 100 percent blade radius, and where the blade angle between the blade element chord axis and line tangent to the vortex-trail becomes large.

2. Forward Flight - In forward flight, where the rotor advance ratio becomes important, each airspeed had to be considered separately. Only the intersections for the initial 240 degrees of trailed filament are considered. The emphasis is on the intersection points where the blade and vortex paths approach tangency.

### Z AXIS

Once the possible intersections in the X-Y plane are established, the next step is to determine the relationship of the blade-vortex in the vertical plane, for at this point an intersection can occur only if the vertical position of the vortex filament coincides with that of a blade element. Only hover and straight, level forward flight cases were considered in this study. The aircraft motion along the Y and Z axes was zero in all cases. The geometry of the blade shedding the vortices and the possible intersecting blade element for any particular rotor azimuth location is obtained by computing the total blade flapping.

$$\beta_z = a_o - a_1 \cos \psi - b_1 \sin \psi + i_s \cos \psi \qquad (3)$$

where

$a_o$ = rotor blade mean coning angle with respect to the rotor disc plane.

$a_1$ = first harmonic longitudinal flapping angle with respect to the rotor disc plane.

$b_1$ = first harmonic lateral flapping angle with respect to the rotor disc plane.

$i_s$ = angle of incidence of the rotor shaft in the helicopter X-Z plane.

$\psi$ = azimuth position of the blade.

The coordinates for a point on the vortex filament are then found by resolving the vector into its components (normalized to radius r)

$$C_x = \cos \beta_\psi \cos \psi + P(\mu_x) \frac{\Delta\psi}{360} (2\pi) \quad (4)$$

$$C_y = -\cos \beta_\psi \sin \psi + P(\mu_y) \frac{\Delta\psi}{360} (2\pi) \quad (5)$$

$$C_z = -\sin \beta_\psi + P(\mu_z + \lambda_z) \frac{\Delta\psi}{360} (2\pi) \quad (6)$$

where

$\beta_\psi$ = the azimuth position on the blade occupied when shedding the vortices; obtained from the geometrical representations.

$\Delta\psi$ = the equal blade azimuth angle steps to be considered along the vortex trail (in this study was 30°).

$\mu$ = rotor advance ratio with respect to the rotor disc plane.

$\lambda$ = rotor inflow ratio with respect to the rotor disc plane.

P = the order of points to be computed in equal increments of $\psi$ in obtaining the geometry of the filaments.

The origin of the coordinates is the hub of the rotor. With no lateral motion of the aircraft, in cases studied, $\mu_y$ and the last term of $C_y$ become zero.

In stabilized hover cases, where $\mu_x$ approaches zero, only the first terms of the components $c_x$ and $c_y$ are considered. For forward flight where both the rotor advance ratio and blade geometry become important, the full terms of $C_x$ and $C_z$ are computed. Upon resolution of the appropriate components, the vortex filaments were traced as a function of blade azimuth angle increments (vertical position being defined as $Z_v$ with respect to the forward rotor hub). The possibility of a blade from the opposing rotor intersecting this filament was determined by computing its vertical position (also with respect to the forward rotor hub and defining it as $Z_\beta$). The subsequent differential in height is $\bar{Z}$ where $\bar{Z} = Z_\beta - Z_v$ with $\bar{Z}$ positive when the blade element is above the filament and negative when below. $\bar{Z} = 0$ indicates a calculated intersection in the X-Z plane.

The method described provides the ability to calculate blade-vortex separations. Although the simplifying assumptions listed below are inherent in the calculation, the results appear to correlate with the measured noise levels. The major assumptions are:

1. The blade reacts like a rigid body.

2. The trailed wake does not distort.

Assumption number 2 is valid within 60 degrees of rotation after the vortex is shed, where blade-vortex intersections generally occur.

## APPENDIX II

## FLIGHT TEST PROGRAM, PHASES I AND II

This appendix presents the specific data points and operating conditions obtained during both Phase I and Phase II of this program. The 'Run' conditions are to be used in identifying all data presented in Appendixes III, IV, and V.

TABLE III. FLIGHT TEST PROGRAM - PHASE I

| Run | Run Gross Weight (lb) | Run CG (in. fwd) | True Air-speed (kn) | Rotor RPM | Longitudinal Cyclic Trim (deg) (Nominal) Fwd | Aft | Fuselage Attitude (deg) Pitch | Roll | Side-slip |
|---|---|---|---|---|---|---|---|---|---|
| Flight No. 393 | | | | | | | | | |
| 1 | 36,873 | 3.6 | 27 | 230 | -0.5 | 0.0 | 5.3 | -3.7 | +0.4 |
| 2 | 36,823 | 3.6 | 27 | 231 | -0.5 | 0.0 | 5.3 | +0.5 | -7.5 |
| 3 | 36,823 | 3.6 | 27 | 229 | -0.5 | 0.0 | 5.3 | -1.1 | -15 |
| 4 | 36,773 | 3.6 | 27 | 231 | -0.5 | 0.0 | 5.3 | +0.3 | +7.5 |
| 5 | 36,773 | 3.6 | 27 | 231 | -0.5 | 0.0 | 5.3 | +0.8 | +15 |
| 6 | 36,573 | 3.5 | 28 | 231 | -0.5 | 0.0 | 4.9 | -0.8 | -0.2 |
| 7 | 36,473 | 3.5 | 28 | 229 | -0.5 | 0.0 | 5.2 | -0.2 | +7.5 |
| 8 | 36,423 | 3.4 | 28 | 231 | -0.5 | 0.0 | 5.0 | +0.4 | +15 |
| 9 | 36,373 | 3.4 | 28 | 229 | -0.5 | 0.0 | 5.0 | +1.8 | +30 |
| 10 | 36,323 | 3.4 | 28 | 229 | -0.5 | 0.0 | 5.0 | -1.6 | -15 |
| 11 | 36,273 | 3.4 | 25 | 231 | -0.5 | 0.0 | 5.2 | -2.4 | -30 |
| 12 | 35,973 | 3.3 | 63 | 231 | -0.5 | 0.0 | 2.7 | -0.7 | 0.0 |
| 13 | 35,923 | 3.3 | 70 | 241 | -0.5 | 0.0 | 2.4 | -0.9 | +0.1 |
| 14 | 35,873 | 3.3 | 59 | 240 | -0.5 | 0.0 | 3.0 | +0.3 | -0.1 |
| 15 | 35,273 | 3.1 | 57 | 231 | -0.5 | 0.0 | 3.0 | +0.2 | +0.1 |
| 16 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 17 | 35,123 | 3.0 | 0 | 229 | -0.5 | 0.0 | 2.2 | -2.8 | -0.3 |
| 18 | 35,073 | 3.0 | 0 | 230 | -0.5 | 0.0 | 3.5 | -1.5 | 0.0 |
| 19 | 35,023 | 3.0 | 0 | 230 | -0.5 | 0.0 | 3.4 | -0.2 | 0.1 |
| 20 | 34,998 | 3.0 | 0 | 229 | -0.5 | 0.0 | 3.3 | +0.1 | -0.4 |
| 21 | 34,973 | 3.0 | 0 | 231 | -0.5 | 0.0 | 3.4 | +0.6 | -0.1 |
| Flight No. 394 | | | | | | | | | |
| 0 | 33,200 | 5.3 | 0 | 231 | -0.5 | -0.8 | - | -1.3 | +5.5 |
| 1 | 33,300 | 5.3 | 58 | 231 | -0.8 | -0.8 | +2.8 | -1.2 | -2.4 |
| 2 | 33,200 | 5.3 | 101 | 231 | -1.3 | -1.0 | -0.8 | +0.4 | +0.2 |
| 3 | 33,200 | 5.3 | 85 | 231 | -1.0 | -1.0 | +1.3 | +0.3 | -2.3 |
| 4 | 33,150 | 5.3 | 99 | 230 | -2.5 | -2.8 | +1.3 | -0.6 | -3.9 |
| 5 | 33,100 | 5.2 | 100 | 229 | -3.0 | -4.9 | +3.3 | -1.5 | -3.5 |
| 6 | 33,050 | 5.2 | 101 | 229 | -3.5 | -5.8 | +3.4 | -1.7 | -4.0 |

TABLE III - Continued

| Run | Run Gross Weight (lb) | Run CG (in. fwd) | True Air-Speed (kn) | Rotor RPM | Longitudinal Cyclic Trim (deg) (Nominal) Fwd | Aft | Fuselage Attitude (deg) Pitch | Roll | Side-slip |
|---|---|---|---|---|---|---|---|---|---|
| **Flight No. 394 (Continued)** | | | | | | | | | |
| 7 | 33,000 | 5.2 | 76 | 222 | -1.2 | -1.0 | +1.2 | -1.7 | -9.0 |
| 8 | 32,950 | 5.2 | 59 | 214 | -1.1 | -0.9 | +2.0 | -0.1 | -5.2 |
| 9 | 32,850 | 5.2 | 59 | 213 | -1.2 | -0.9 | +4.2 | -0.8 | -6.2 |
| 10 | - | - | - | - | - | - | +2.3 | - | - |
| 11 | 32,700 | 5.1 | 28 | 202 | -0.9 | -0.8 | +4.4 | -1.7 | -8.9 |
| 12 | 32,550 | 5.1 | 28 | 202 | -0.5 | -0.8 | +4.1 | -2.1 | -4.8 |
| 13 | 32,500 | 5.1 | 28 | 202 | -2.0 | -2.3 | +6.3 | -2.1 | -13.0 |
| 14 | 32,450 | 5.1 | 82 | 235 | -1.0 | -1.1 | +1.4 | -0.2 | -3.9 |
| 15 | 32,300 | 5.0 | 99 | 231 | -1.1 | -1.8 | +3.3 | - | - |
| 16 | 32,150 | 5.0 | 59 | 231 | -2.6 | -4.7 | - | -1.0 | -15.2 |
| **Flight No. 395** | | | | | | | | | |
| 2 | 25,600 | -0.2 | 0 | 230 | -0.7 | -0.7 | +7.1 | 0.0 | -3.9 |
| 3 | 25,500 | -0.3 | 54 | 229 | -1.1 | -0.9 | +2.5 | 0.0 | -3.2 |
| 4 | 25,450 | -0.3 | 98 | 229 | -3.3 | -5.2 | +4.1 | +0.7 | -0.7 |
| 5 | 25,450 | -0.3 | 138 | 229 | -3.9 | -5.4 | -0.8 | -1.1 | -2.4 |
| 6 | 25,400 | -0.3 | 55 | 204 | -1.3 | -0.8 | +3.2 | -0.8 | -4.0 |
| 7 | 25,200 | -0.5 | 53 | 216 | -1.2 | -0.8 | +2.6 | +0.5 | -0.1 |
| 8 | 25,200 | -0.5 | 69 | 216 | -1.3 | -0.9 | +2.5 | -0.2 | -2.6 |
| 9 | 25,200 | -0.5 | 96 | 215 | -3.0 | -3.7 | +2.2 | -3.0 | -1.6 |
| 10 | 25,200 | -0.5 | 102 | 216 | -3.7 | -5.6 | +2.1 | -0.6 | -2.6 |
| 11 | 25,150 | -0.5 | 76 | 229 | -0.8 | -1.1 | +1.4 | -26.4 | - |
| 12 | 25,150 | -0.5 | 74 | 229 | -1.0 | -1.0 | -1.2 | +27.2 | -5.2 |
| 13 | 25,150 | -0.5 | 79 | 229 | -1.2 | -0.8 | +2.9 | +3.4 | -10.9 |
| 14 | 25,100 | -0.5 | 72 | 229 | -0.9 | -1.1 | +1.3 | -2.5 | -9.8 |
| 15 | 24,950 | -0.6 | 77 | 229 | -1.1 | -1.0 | -1.1 | +22.8 | -9.4 |
| 16 | 24,950 | -0.6 | 78 | 229 | -0.9 | -1.0 | +0.8 | +3.9 | -7.4 |
| 17 | 24,950 | -0.6 | 76 | 229 | -0.8 | -0.8 | -18.3 | -13.2 | -2.4 |
| 18 | 24,900 | -0.6 | 72 | 229 | -1.0 | -1.1 | +3.0 | +0.2 | -5.4 |
| 19 | 24,900 | -0.6 | 73 | 227 | -1.1 | -0.9 | +3.8 | -0.4 | - |
| **Flight No. 398** | | | | | | | | | |
| 1 | 23,900 | 3.2 | 129 | 225 | -3.3 | -5.2 | -2.8 | 3.5 | 4.0 |
| 2 | 23,850 | 3.2 | 138 | 225 | -3.3 | -5.2 | -6.1 | 1.0 | 2.4 |
| 3 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 4 | 23,700 | 3.1 | 126 | 235 | -3.1 | -5.2 | -1.4 | -0.4 | 1.9 |
| 5 | 23,650 | 3.1 | 133 | 235 | -3.3 | -5.3 | -3.8 | 0.6 | 1.3 |
| 6 | 23,600 | 3.0 | 147 | 235 | -3.4 | -5.3 | -5.6 | 1.0 | 3.9 |
| 7 | 23,550 | 3.0 | 122 | 230 | -3.1 | -5.1 | -1.8 | 1.0 | 1.7 |
| 8 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9 | 23,400 | 2.9 | 148 | 230 | -3.4 | -5.4 | -5.7 | 0.3 | 2.5 |

TABLE IV. FLIGHT TEST PROGRAM - PHASE II

| Run | Run Gross Weight (lb) | Run CG (in. fwd) | True Air-speed (kn) | Rotor RPM | Longitudinal Cyclic Trim (deg) (Nominal) Fwd | Aft | Fuselage Attitude (deg) Pitch | Roll | Side-slip |
|---|---|---|---|---|---|---|---|---|---|
| **Flight No. 399** | | | | | | | | | |
| 1 | 29,000 | 5.2 | 109 | 230 | 3.55 | 4.63 | -0.70 | 0.30 | 4.40 |
| 2 | 28,200 | 4.9 | 128 | 230 | 3.60 | 5.62 | -1.69 | -1.83 | -2.22 |
| 3 | 28,000 | 4.9 | 128 | 230 | 3.65 | 5.53 | -0.68 | -1.24 | 0.37 |
| 4 | 27,850 | 4.8 | 0 | 230 | 0.60 | 0.74 | 6.27 | -0.08 | 27.36 |
| 5 | 27,850 | 4.8 | 0 | 230 | 0.93 | 0.59 | 6.75 | -2.03 | -52.45 |
| 6 | 27,850 | 4.8 | 0 | 230 | 0.97 | 0.57 | 7.40 | -1.84 | 14.59 |
| 7 | 27,750 | 4.8 | 0 | 230 | 0.76 | 0.55 | 7.36 | -2.67 | 70.73 |
| 8 | 27,700 | 4.8 | 0 | 230 | 2.93 | 4.97 | 10.61 | -0.86 | 26.04 |
| 9 | 27,700 | 4.8 | 0 | 230 | 2.95 | 4.93 | 10.73 | -1.81 | -24.44 |
| 10 | 27,650 | 4.7 | 0 | 230 | 3.07 | 4.90 | 10.59 | -2.51 | -30.53 |
| 11 | 27,600 | 4.7 | 0 | 230 | 2.98 | 4.94 | 11.65 | -2.59 | -48.91 |
| 12 | 27,600 | 4.7 | 43 | 230 | 3.17 | 5.11 | 10.32 | -1.13 | -15.67 |
| 13 | 27,500 | 4.7 | 85 | 230 | 3.25 | 5.36 | 5.76 | -4.24 | -4.53 |
| 14 | 27,500 | 4.7 | 127 | 230 | 3.53 | 5.54 | 3.74 | -1.37 | -1.92 |
| 15 | 27,400 | 4.7 | 138 | 230 | 3.82 | 5.45 | -1.53 | -1.22 | 0.77 |
| 16 | 27,300 | 4.6 | 43 | 230 | 0.84 | 0.71 | 7.66 | -1.061 | -3.40 |
| 17 | 27,200 | 4.6 | 85 | 230 | 1.37 | 1.35 | 3.19 | -0.69 | -2.92 |
| 18 | 27,000 | 4.5 | 43 | 230 | 3.06 | 4.98 | 7.29 | 0.36 | 1.32 |
| 19 | 26,924 | 4.5 | 85 | 230 | 3.41 | 5.17 | 6.00 | 3.14 | 1.67 |
| 20 | 26,900 | 4.5 | 128 | 230 | 3.80 | 5.42 | 1.63 | 2.14 | 1.71 |
| 21 | 26,800 | 4.5 | 138 | 230 | 3.52 | 5.75 | -1.93 | 0.004 | -1.93 |
| 22 | 26,700 | 4.4 | 43 | 230 | 0.81 | 0.71 | 6.99 | 0.75 | 0.63 |
| 23 | 26,700 | 4.4 | 85 | 230 | 1.80 | 1.85 | -0.87 | -0.09 | 4.28 |
| 24 | 26,650 | 4.4 | 64 | 230 | 1.23 | 1.11 | 17.32 | -2.30 | -20.06 |
| 25 | 26,600 | 4.4 | 117 | 230 | 2.41 | 3.62 | 14.40 | 0.69 | -1.64 |
| 26 | 26,550 | 4.4 | 140 | 230 | 3.91 | 5.48 | -2.40 | 0.30 | 2.82 |
| 27 | 26,550 | 4.4 | 110 | 220 | 2.91 | 3.99 | -2.62 | 1.00 | 1.81 |
| **Flight No. 400** | | | | | | | | | |
| 2 | 28,250 | 4.6 | 0 | 230 | 0.75 | 0.68 | 6.77 | -1.75 | 26.48 |
| 3 | 28,250 | 4.6 | 0 | 230 | 0.68 | 0.65 | 7.93 | -3.16 | -8.16 |
| 4 | 28,200 | 4.6 | 0 | 230 | 0.83 | 0.63 | 8.01 | -3.38 | -6.17 |
| 5 | 28,200 | 4.6 | 0 | 230 | 0.80 | 0.62 | 7.05 | -2.64 | 15.96 |
| 6 | 28,150 | 4.6 | 0 | 230 | 2.96 | 5.03 | 10.93 | -2.49 | 10.22 |
| 7 | 28,100 | 4.6 | 0 | 230 | 2.96 | 4.98 | 11.31 | -2.22 | -14.75 |
| 8 | 28,050 | 4.6 | 0 | 230 | 2.97 | 4.98 | 11.63 | -3.36 | -51.4 |
| 9 | 28,000 | 4.5 | 0 | 230 | 3.01 | 5.04 | 12.04 | -2.95 | -23.65 |
| 10 | 28,000 | 4.5 | 126 | 230 | 3.38 | 5.32 | 1.11 | -1.18 | 1.14 |
| 11 | 28,000 | 4.5 | 126 | 230 | 3.40 | 5.43 | 0.38 | -4.03 | 0.10 |
| 12 | 27,850 | 4.5 | 43 | 230 | 3.14 | 5.16 | 7.54 | -1.51 | -20.82 |
| 13 | 27,850 | 4.5 | 84 | 230 | 3.16 | 5.18 | 7.26 | -3.62 | -2.14 |
| 14 | 27,800 | 4.5 | 126 | 230 | 3.67 | 5.37 | 3.38 | -0.06 | 1.19 |

TABLE IV - Continued

| Run | Run Gross Weight (lb) | Run CG (in. fwd) | True Air-speed (kn) | Rotor RPM | Longitudinal Cyclic Trim (deg) (Nominal) Fwd | Aft | Fuselage Attitude (deg) Pitch | Roll | Side-slip |
|---|---|---|---|---|---|---|---|---|---|
| Flight No. 400 (Continued) | | | | | | | | | |
| 15 | 27,700 | 4.4 | 136 | 230 | 3.63 | 5.48 | 0.13 | -0.97 | 1.34 |
| 16 | 27,600 | 4.4 | 42 | 230 | 1.25 | 0.94 | 4.81 | -1.90 | -19.76 |
| 17 | 27,550 | 4.4 | 84 | 230 | 1.03 | 0.94 | 0.93 | -2.13 | -3.88 |
| 18 | 27,500 | 4.4 | 42 | 230 | 2.89 | 5.15 | 9.82 | 0.06 | -2.99 |
| 19 | 27,500 | 4.4 | 84 | 230 | 3.19 | 5.20 | 4.25 | -1.24 | -0.66 |
| 20 | 27,450 | 4.4 | 125 | 230 | 3.63 | 5.38 | 0.61 | 1.03 | 2.01 |
| 21 | 27,450 | 4.4 | 136 | 230 | 3.65 | 5.39 | -1.107 | -0.71 | 1.54 |
| 22 | 27,400 | 4.3 | 42 | 230 | 0.91 | 0.64 | 3.55 | -0.64 | 2.99 |
| 23 | 27,100 | 4.2 | 84 | 230 | 1.54 | 0.79 | 0.14 | 0.02 | 4.22 |
| 24 | 27,100 | 4.2 | 63 | 230 | 0.78 | 0.82 | 16.29 | -1.33 | -5.52 |
| 25 | 26,800 | 4.1 | 84 | 230 | 0.91 | 0.98 | -1.92 | -3.37 | -2.83 |
| 26 | 26,750 | 4.1 | 110 | 230 | 3.22 | 5.16 | 18.48 | -2.96 | -0.64 |

## APPENDIX III

## AIRBORNE NOISE DATA

TABLE V. AIRBORNE NOISE DATA - LEFT-HAND MICROPHONE

| Run | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| Flight No. 393 | | | | | | | |
| 1 | 132 | 129 | 131 | 126 | 122.5 | 119 | 115 |
| 2 | 133 | 130 | 132 | 126.5 | 124 | 118 | 116 |
| 3 | 132.5 | 129.5 | 133 | 128 | 124 | 119 | 127.5 |
| 4 | 131.5 | 131.5 | 132 | 126 | 124 | 117 | 113.5 |
| 5 | 134 | 129 | 134.5 | 125 | 125 | 119.5 | 112 |
| 6 | 131 | 126 | 132 | 125 | 120.5 | 108 | 115.5 |
| 7 | 133 | 129 | 132 | 128 | 124 | 117.5 | 116 |
| 8 | 133.5 | 130.5 | 133.5 | 126.5 | 126.5 | 121 | 119.5 |
| 9 | 133.5 | 132.5 | 132 | 127.5 | 126 | 122 | 121 |
| 10 | 131.5 | 126.5 | 133.5 | 125 | 121 | 117 | 114 |
| 11 | 133.5 | 128 | 133 | 128 | 123 | 119 | 115 |
| 12 | 133 | 127 | 130.5 | 124 | 120.5 | 114 | 107.5 |
| 13 | 130 | 134 | 124 | 124 | 114.5 | 113.5 | 107.5 |
| 14 | 132.5 | 130.5 | 132 | 127.5 | 120.5 | 113 | 112.5 |
| 15 | 113 | 130.5 | 132.5 | 127.5 | 122.5 | 122 | 118 |
| 16 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 17 | 133 | 128.5 | 131 | 125.5 | 123.5 | 118.5 | 116.5 |
| 18 | 131 | 129 | 129.5 | 126.5 | 126 | 122 | 118.5 |
| 19 | 130 | 126.5 | 129.0 | 125 | 125 | 123 | 119.5 |
| 20 | 128.5 | 126.5 | 128 | 126.5 | 127.5 | 127.5 | 120.5 |
| 21 | 130 | 126 | 130 | 124.5 | 125.5 | 120.5 | 116.5 |
| Flight No. 394 | | | | | | | |
| 0 | (Calibration run - no acoustical data.) | | | | | | |
| 1 | 132 | 127 | 128.5 | 122 | 120 | 117 | 114 |
| 2 | 130 | 127 | 133 | 126.5 | | 111.5 | 109 |
| 3 | 132 | 127.5 | 127.5 | 124 | 116 | 113.5 | 109.5 |
| 4 | 130.5 | 127.0 | 132.5 | 128.5 | 120.5 | 116.5 | 111 |
| 5 | 134.5 | 129 | 129 | 124.5 | 119 | 111.5 | 108.5 |
| 6 | 133.5 | 131.5 | 134.5 | 131 | 125.5 | 120 | 116.5 |
| 7 | 134.5 | 132.5 | 136.5 | 130.5 | 124 | 120 | 114 |
| 8 | 128 | 124 | 127 | 124 | 115.5 | 111 | 107.5 |
| 9 | 131.5 | 128 | 135 | 130 | 123.5 | 120 | 115.5 |
| 10 | 127.5 | 124 | 129.5 | 125.5 | 116.5 | 112.5 | 107.5 |
| 11 | 130.5 | 125 | 130 | 122.5 | 116 | 118.5 | 114.5 |
| 12 | 128.5 | 122.5 | 129 | 121 | 113 | 113.5 | 105.5 |
| 13 | 130 | 124 | 129.5 | 120.5 | 114 | 112.5 | 108 |

TABLE V - Continued

| Run | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| Flight No. 394 (Continued) | | | | | | | |
| 14 | 130 | 124 | 128 | 127 | 119 | 115 | 109 |
| 15 | 132.5 | 130.5 | 133.5 | 131 | 122.5 | 118 | 113.5 |
| 16 | 129 | 123 | 126.5 | 123 | 113 | 107.5 | 106 |
| Flight No. 395 | | | | | | | |
| 2 | 131 | 128.5 | 133 | 126.5 | 121.5 | 118.5 | 114.5 |
| 3 | 130 | 126 | 128 | 121 | 122.5 | 119 | 117.5 |
| 4 | 127.5 | 126 | 130.5 | 126.5 | 121 | 119 | 111 |
| 5 | 134 | 132 | 136.5 | 129.5 | 118 | 114 | 111.5 |
| 6 | 134.5 | 131 | 130.5 | 124.5 | 118.5 | 115 | 112 |
| 7 | 127.5 | 123.5 | 127.5 | 119.5 | 113 | 108.5 | 102 |
| 8 | 138 | 126.5 | 134.5 | 126 | 119 | 116.5 | 112 |
| 9 | 127.5 | 125 | 130 | 125 | 120 | 113.5 | 113 |
| 10 | 132 | 129 | 131.5 | 122 | 117.5 | 114.5 | 114 |
| 11 | 134 | 130.5 | 137.5 | 131.5 | 122 | 118 | 112.5 |
| 12 | 128 | 120 | 119 | 126.5 | 119.5 | 113 | 110.5 |
| 13 | 128 | 126 | 131 | 123.5 | 116.5 | 109.5 | 112 |
| 14 | 135.5 | 133.5 | 131 | 128.5 | 122.5 | 120.5 | 118 |
| 15 | 126.5 | 121.0 | 126.5 | 126 | 116 | 116 | 112 |
| 16 | 127 | 126 | 129.5 | 128.5 | 117.5 | 117 | 114 |
| 17 | 127 | 124 | 127.5 | 129 | 118.5 | 115.5 | 112 |
| 18 | 131.5 | 128 | 129.5 | 123 | 122.5 | 116.5 | 113.5 |
| 19 | 127 | 126 | 132.5 | 127.5 | 123 | 115.5 | 121 |
| Flight No. 398 | | | | | | | |
| 1 | 134.5 | 135 | 137.5 | 137 | 136.5 | 135 | 134.5 |
| 2 | 133.5 | 134 | 135 | 135 | 134.5 | 135.5 | 136 |
| 3 | 131.5 | 130.5 | 133.5 | 135.5 | 139.5 | 138.5 | 139.5 |
| 4 | 135.5 | 136 | 143 | 146 | 143 | 139 | 138 |
| 5 | 134.5 | 135.5 | 138.5 | 138 | 135 | 136 | 136.5 |
| 6 | 136 | 134.5 | 135.5 | 137.5 | 138.5 | 138.5 | 140.5 |
| 7 | 136 | 135.5 | 142.5 | 145.5 | 139.5 | 136 | 134.5 |
| 8 | 135 | 135 | 135.5 | 136 | 133.5 | 135 | 133.5 |
| 9 | 134 | 133 | 134 | 136.5 | 137.5 | 137.5 | 138.5 |
| Flight No. 399 | | | | | | | |
| 1 | 144 | 133 | 137 | 131 | 124.5 | 120 | 115.5 |
| 2 | 132 | 129.5 | 126.5 | 122 | 115.5 | 113.5 | 113 |
| 3 | 133 | 131 | 127.5 | 121 | 117 | 113.5 | 112.5 |

TABLE V - Continued

| Run | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| Flight No. 399 (Continued) | | | | | | | |
| 4 | 129 | 126.5 | 127 | 123.5 | 122 | 117.5 | 116 |
| 5 | 131 | 127.5 | 132 | 125 | 120 | 116 | 113 |
| 6 | 131 | 128 | 132.5 | 125 | 121.5 | 115 | 112.5 |
| 7 | 129.5 | 126.5 | 131 | 124 | 119 | 114 | 112.5 |
| 8 | 128 | 125.5 | 128 | 122.5 | 116 | 112 | 110 |
| 9 | 132 | 129 | 130.5 | 122.5 | 118 | 115.5 | 111.5 |
| 10 | 130 | 126.5 | 130 | 124 | 119.5 | 116.5 | 114 |
| 11 | 130 | 125.5 | 129 | 124 | 119 | 113 | 113 |
| 12 | 129 | 127.5 | 126 | 122 | 116 | 112 | 108.5 |
| 13 | 129 | 128 | 132 | 128 | 121.5 | 115.5 | 112 |
| 14 | 132 | 131 | 127 | 125 | 119 | 118.5 | 115.5 |
| 15 | 132 | 129 | 125.5 | 125.5 | 123 | 119 | 116 |
| 16 | 127.5 | 125 | 130 | 125 | 120.5 | 115.5 | 111.5 |
| 17 | 127 | 125 | 127.5 | 128 | 118.5 | 115 | 113 |
| 18 | 127 | 126 | 131 | 127.5 | 119.5 | 113 | 110 |
| 19 | 131 | 126.5 | 134 | 128 | 121 | 114 | 111 |
| 20 | 134 | 133 | 128 | 124 | 122 | 118 | 113.5 |
| 21 | 132 | 130 | 126 | 124 | 119 | 118 | 114 |
| 22 | 127.5 | 127.5 | 132 | 128.5 | 122.5 | 116 | 117 |
| 23 | 133 | 128 | 125.5 | 122 | 116.5 | 114 | 112 |
| 24 | 129 | 125 | 129.5 | 122 | 116.5 | 112 | 107 |
| 25 | 132 | 130.5 | 127 | 120 | 117 | 114 | 111 |
| 26 | 133.5 | 132 | 127.5 | 123 | 117.5 | 113.5 | 112 |
| 27 | 133 | 128.5 | 127.5 | 118.5 | 111.5 | 119.5 | 108 |
| Flight No. 400 | | | | | | | |
| 2 | 130.5 | 127 | 127.5 | 123 | 119 | 114.5 | 112.5 |
| 3 | 130.5 | 129.5 | 117 | 121 | 118.5 | 114 | 112.5 |
| 4 | 130 | 126 | 128 | 121.5 | 120.5 | 115.5 | 112.5 |
| 5 | 129 | 127 | 127.5 | 123.5 | 118 | 114 | 112 |
| 6 | 131 | 124 | 126 | 120 | 117 | 114 | 112.5 |
| 7 | 129.5 | 125.5 | 126 | 121.5 | 119.5 | 116.5 | 114 |
| 8 | 129 | 125.5 | 126.5 | 122 | 120 | 116 | 113 |
| 9 | 128 | 125 | 117 | 121 | 119 | 115 | 113.5 |
| 10 | 133.5 | 130.5 | 130 | 125 | 118 | 114 | 114 |
| 11 | 132 | 129 | 125 | 124 | 118.5 | 116 | 124.5 |
| 12 | 129 | 125 | 124 | 119 | 117 | 115 | 113 |
| 13 | 127 | 124.5 | 127 | 121 | 118 | 116 | 113 |
| 14 | 135 | 129.5 | 132.5 | 127.5 | 120 | 112 | 115.5 |
| 15 | 132 | 129 | 125 | 125 | 124 | 117 | 118 |
| 16 | 130 | 126.5 | 126 | 122 | 118.5 | 113.5 | 112 |

TABLE V - Continued

| Run | Octave Band Center Frequencies - Hz | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| | (Sound pressure level in db given below) | | | | | | |
| Flight No. 400 (Continued) | | | | | | | |
| 17 | 125 | 125 | 123 | 121 | 115.5 | 112.5 | 112 |
| 18 | 123 | 125 | 124 | 119 | 115.5 | 112.5 | 112 |
| 19 | 123.5 | 125 | 127 | 122 | 118 | 113 | 111.5 |
| 20 | 135 | 130 | 130 | 126 | 118 | 116 | 114 |
| 21 | 134 | 131 | 128.5 | 126 | 120 | 117.5 | 115.5 |
| 22 | 125 | 123 | 129 | 122 | 120.5 | 115.5 | 113.5 |
| 23 | 128.5 | 128 | 129.5 | 125 | 118 | 116 | 112.5 |
| 24 | 123.5 | 121 | 121 | 118.5 | 115 | 113 | 112.5 |
| 25 | 127 | 125 | 124.5 | 119.5 | 113 | 111 | 111.5 |
| 26 | 133 | 130 | 132.5 | 126.5 | 121 | 116 | 111.5 |

| TABLE VI. AIRBORNE NOISE DATA - NOSE-BOOM MICROPHONE | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Octave Band Center Frequencies - Hz | | | | | | |
| Run | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| | (Sound pressure level in db given below) | | | | | | |
| Flight No. 393 | | | | | | | |
| 1 | 119 | 119.5 | 123.5 | 120 | 120 | 114 | 113.5 |
| 2 | 119 | 122 | 124 | 121.5 | 117 | 112.5 | 109.5 |
| 3 | 120 | 123.5 | 127 | 123 | 120 | 118.5 | |
| 4 | 120 | 122.5 | 125.5 | 121.5 | 117 | 115 | 110 |
| 5 | 120 | 121.5 | 123 | 121 | 117.5 | 113.5 | 108 |
| 6 | 117.5 | 113.5 | 120.5 | 117 | 113.5 | 109.5 | 105.5 |
| 7 | 116 | 115.5 | 119.5 | 115.5 | 117 | 109 | 106.5 |
| 8 | 117.5 | 116 | 120 | 115 | 114 | 108 | 106 |
| 9 | 118.5 | 115.5 | 119 | 116 | 113 | 110.5 | 105.5 |
| 10 | 117.5 | 113 | 118 | 117.5 | 117.5 | 115 | 110.5 |
| 11 | 119.5 | 121.5 | 125 | 123.5 | 120.5 | 119 | 115.5 |
| 12 | 115.5 | 114 | 118 | 119 | 112.5 | 114 | 109 |
| 13 | 117 | 115 | 1122 | 120.5 | 115 | 114.5 | 108 |
| 14 | 116.5 | 115 | 121 | 120 | 117.5 | 115.5 | 110.5 |
| 15 | 118.5 | 119.5 | 123 | 119.5 | 120 | 117.5 | 113.5 |
| 16 | - | - | - | - | - | - | - |
| 17 | 118.5 | 119.5 | 123 | 121 | 118.5 | 115.5 | 113 |
| 18 | 120 | 116.5 | 122 | 118 | 116.5 | 119.5 | 112 |
| 19 | 118 | 117.5 | 121 | 117 | 115 | 12.5 | 107 |
| 20 | 117.5 | 116 | 119 | 116.5 | 113 | 109.5 | 104 |
| 21 | 117 | 114.5 | 118 | 114.5 | 113.5 | 114 | 108 |
| Flight No. 394 | | | | | | | |
| 1 | 117 | 120 | 122.5 | 121.5 | 122.5 | 117.5 | 111 |
| 2 | 118.5 | 119.5 | 126.5 | 121.5 | 120 | 118 | 114 |
| 3 | 118.5 | 119 | 122.5 | 122 | 119 | 119.5 | 114.5 |
| 4 | 119 | 121 | 123 | 122 | 119 | 118 | 114.5 |
| 5 | 120.5 | 124.5 | 129 | 127.5 | 125.5 | 122 | 120.5 |
| 6 | 119.5 | 123.5 | 132.5 | 129 | 125 | 124.5 | 122 |
| 7 | 118 | 118 | 123 | 119.5 | 117.5 | 113.5 | 110.5 |
| 8 | - | - | - | - | - | - | - |
| 9 | 117 | 116.5 | 123 | 122 | 118 | 115.5 | 109.5 |
| 10 | 118.5 | 116 | 123 | 121.5 | 118 | 115 | 109.5 |
| 11 | 114.5 | 116 | 119 | 118 | 119 | 112 | 109 |
| 12 | 113.5 | 111 | 116 | 114 | 113.5 | 111.5 | 105.5 |
| 13 | 116 | 116 | 118 | 117 | 117.5 | 114 | 108.5 |
| 14 | 116.5 | 114.5 | 123 | 119 | 117 | 116 | 114 |
| 15 | 121.5 | 123 | 131.5 | 129.5 | 125 | 124 | 121 |
| 16 | 121 | 122 | 122 | 119 | 117.5 | 114 | 109.5 |

TABLE VI - Continued

| Run | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| Flight No. 395 | | | | | | | |
| 2 | 119 | 119.5 | 123.5 | 120 | 121 | 118 | 117 |
| 3 | 117.5 | 115 | 122 | 122 | 121.5 | 119 | 114 |
| 4 | 120.5 | 125 | 134 | 128.5 | 127 | 124 | 121.5 |
| 5 | 123 | 123 | 129 | 127.5 | 125.5 | 123.5 | 121.5 |
| 6 | 117.5 | 114.5 | 120 | 117 | 114 | 111.5 | 107 |
| 7 | 117 | 117 | 121 | 120 | 114.5 | 113 | 109.5 |
| 8 | 118.5 | 116 | 120 | 119 | 117 | 113 | 109 |
| 9 | 119.5 | 119.5 | 124 | 124 | 121 | 118.5 | 115.5 |
| 10 | 121.5 | 122 | 128 | 126 | 125 | 124 | 121 |
| 11 | 117.5 | 115 | 122 | 116 | 115 | 113 | 108.5 |
| 12 | 119.5 | 118 | 123.5 | 119 | 118 | 115 | 113 |
| 13 | 118.5 | 118 | 128 | 125 | 119 | 114 | 110 |
| 14 | 118.5 | 114 | 120 | 119 | 116 | 112.5 | 111.5 |
| 15 | 119.5 | 118.5 | 122 | 122.5 | 119 | 117 | 114 |
| 16 | 118.5 | 118.5 | 122 | 121 | 118 | 114 | 112 |
| 17 | 117 | 117 | 119.5 | 118 | 118 | 116 | 111 |
| 18 | 120.5 | 119 | 124.5 | 123 | 122.5 | 120.5 | 115 |
| 19 | 124.5 | 126.5 | 127 | 127 | 125.5 | 125 | 122 |
| Flight No. 398 | | | | | | | |
| 1 | 119.5 | 118.5 | 124.5 | 126.5 | 123 | 120.5 | 117.5 |
| 2 | 119.5 | 120 | 128 | 127 | 123.5 | 124 | 122.5 |
| 3 | 124.5 | 120.5 | 126 | 122 | 127 | 137 | 116 |
| 4 | 123 | 125.5 | 129.5 | 131 | 126.5 | 126.5 | 126 |
| 5 | 123 | 121.5 | 128 | 126.5 | 125.5 | 125 | 123 |
| 6 | 128.5 | 127.5 | 131 | 127.5 | 127.5 | 121 | 119.5 |
| 7 | 123.5 | 127.5 | 129 | 124.5 | 124.5 | 128 | 125.5 |
| 8 | 122 | 121.5 | 127.5 | 127.5 | 125.5 | 125 | 123.5 |
| 9 | 122.5 | 120 | 129.5 | 126 | 122.5 | 122.5 | 120 |
| Flight No. 399 | | | | | | | |
| 1 | 121.5 | 127.5 | 134 | 125 | 128 | 126 | 133 |
| 2 | 122 | 122.5 | 124 | 123 | 121 | 121 | 118 |
| 3 | 122 | 122 | 128 | 126.5 | 127 | 125 | 122.5 |
| 4 | 120.5 | 121 | 122.5 | 122 | 118 | 117 | 112.5 |
| 5 | 120 | 120 | 124 | 119.5 | 119.5 | 116.5 | 113 |
| 6 | 122 | 123 | 126 | 123 | 122.5 | 119 | 114 |
| 7 | 121.5 | 122.5 | 125 | 124 | 119 | 118.5 | 110 |
| 8 | 121 | 121 | 123 | 120.5 | 125 | 112.5 | 109 |
| 9 | 123.5 | 123.5 | 124.5 | 121.5 | 117.5 | 116 | 112 |

TABLE VI - Continued

| Run | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| Flight No. 399 (Continued) | | | | | | | |
| 10 | 120 | 120.5 | 123 | 120 | 114.5 | 114 | 110 |
| 11 | 119 | 122 | 123 | 120.5 | 116.5 | 116 | 116.5 |
| 12 | 119 | 121 | 123.5 | 121.5 | 114.5 | 116 | 112 |
| 13 | 122 | 124 | 127 | 126.5 | 125 | 125 | 121.5 |
| 14 | 124 | 124.5 | 127.5 | 127.5 | 128 | 126.5 | 124 |
| 15 | 122 | 121 | 126.5 | 124 | 123 | 123.5 | 117.5 |
| 16 | 120 | 118.5 | 121 | 122 | 118 | 118 | 113 |
| 17 | 123 | 123 | 125 | 124 | 121.5 | 120 | 122 |
| 18 | 119.5 | 119.5 | 125 | 123 | 122.5 | 119.5 | 116.5 |
| 19 | 120 | 127 | 129 | 127 | 123.5 | 123 | 120.5 |
| 20 | 124 | 128 | 131 | 128 | 130 | 128 | 125.5 |
| 21 | 123 | 124 | 127 | 126 | 122.5 | 124 | 119.5 |
| 22 | 120.5 | 121.5 | 123 | 119.5 | 119 | 119 | 116 |
| 23 | 120 | 117.5 | 119.5 | 117 | 115 | 115 | 111 |
| 24 | 123 | 125 | 126 | 125.5 | 120 | 118 | 111.5 |
| 25 | 121 | 118.5 | 124.5 | 123 | 117 | 116.5 | 112.5 |
| 26 | 122.5 | 124 | 129 | 128 | 126 | 126 | 121.5 |
| 27 | 122 | 123.5 | 127 | 125 | 124 | 123 | |
| Flight No. 400 | | | | | | | |
| 2 | 120.5 | 122 | 121.5 | 121.5 | 118 | 115 | 110 |
| 3 | 121 | 122 | 123 | 121.5 | 117.5 | 115 | 112 |
| 4 | 121.5 | 121 | 123 | 120 | 117.5 | 116.5 | 111.5 |
| 5 | 118.5 | 120 | 122 | 119 | 115 | 112 | 109 |
| 6 | 122 | 115 | 123 | 121.5 | 119 | 115.5 | 114.5 |
| 7 | 118 | 123 | 123 | 119 | 114.5 | 112 | 110.5 |
| 8 | 118 | 121.5 | 123.5 | 118 | 116 | 114 | 111.5 |
| 9 | 117 | 121 | 121 | 116.5 | 113.5 | 112 | 110 |
| 10 | 120.5 | 124.5 | 130 | 126.5 | 124.5 | 123.5 | 118 |
| 11 | 121.5 | 123 | 128 | 126 | 124 | 123 | 117 |
| 12 | 120 | 124 | 124 | 116.5 | 117 | 115 | 110 |
| 13 | 120.5 | 121 | 125.5 | 124.5 | 120 | 119 | 114 |
| 14 | 124.5 | 126.5 | 131 | 128.5 | 126 | 124 | 118 |
| 15 | 123 | 126 | 131 | 129 | 124 | 124 | 118.5 |
| 16 | 122 | 124 | 124 | 124 | 120 | 118 | 113 |
| 17 | 120 | 123 | 124 | 124 | 122 | 120 | 116 |
| 18 | 117 | 118 | 121 | 118 | 116 | 116.5 | 112.5 |
| 19 | 120.5 | 120 | 124.5 | 124 | 121 | 120.5 | 115.5 |
| 20 | 123 | 127 | 132.5 | 128.5 | 127.5 | 125.5 | 120 |
| 21 | 125.5 | 127 | 132 | 128.5 | 126.5 | 125.5 | 119.5 |
| 22 | 120 | 116 | 122 | 121.5 | 122 | 121 | 115.5 |

TABLE VI - Continued

| Run | Octave Band Center Frequencies - Hz | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| | (Sound pressure level in db given below) | | | | | | |
| Flight No. 400 (Continued) | | | | | | | |
| 23 | 119 | 121 | 125.5 | 124 | 121.5 | 121 | 115 |
| 24 | 122 | 120 | 121.5 | 120 | 117.5 | 114 | 112.5 |
| 25 | 118.5 | 115.5 | 120.5 | 117.5 | 116.5 | 114 | 111.5 |
| 26 | 127.5 | 123 | 128 | 133 | 129.5 | 127 | 120 |

TABLE VII. AIRBORNE NOISE DATA - RIGHT-HAND MICROPHONE

| Run | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| Flight No. 393 | | | | | | | |
| 1 | 126 | 125 | 125 | 121 | 118 | 114.5 | 113 |
| 2 | 125 | 122 | 123 | 119 | 114 | 109 | 110 |
| 3 | 122.5 | 122.5 | 120.5 | 118 | 114 | 111 | 109.5 |
| 4 | 124.5 | 125.5 | 126.5 | 125 | 118 | 113 | 112 |
| 5 | 124.5 | 123 | 127 | 125 | 118 | 113 | 108.5 |
| 6 | 125 | 121.5 | 118.5 | 114.5 | 112 | 110 | 109.5 |
| 7 | 124 | 123.5 | 119.5 | 116 | 113.5 | 111.5 | 112 |
| 8 | 122.5 | 121 | 118 | 115 | 112.5 | 110.5 | 110.5 |
| 9 | 125.5 | 123.5 | 122.5 | 118.5 | 115 | 110.5 | 110.5 |
| 10 | 123.5 | 121.5 | 119.5 | 116 | 113.5 | 110.5 | 110 |
| 11 | 124 | 121 | 118 | 117 | 111 | 110 | 110.5 |
| 12 | 122 | 121 | 121 | 115 | 114 | 111 | 110.5 |
| 13 | 124.5 | 119.5 | 120.5 | 116 | 113 | 111.5 | 111.5 |
| 14 | 124.5 | 122.5 | 124 | 122 | 118.5 | 113.5 | 112 |
| 15 | 129 | 130 | 128 | 127.5 | 128 | 125.5 | 123 |
| 16 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 17 | 130 | 129.5 | 128.5 | 127 | 127 | 124 | 126.5 |
| 18 | 129.5 | 128.0 | 127 | 126 | 121 | 119.5 | 117.5 |
| 19 | 126.5 | 126.5 | 124 | 122 | 122 | 118 | 117 |
| 20 | 127 | 124 | 126 | 123 | 124 | 121 | 118.5 |
| 21 | 125.5 | 127 | 125 | 125.5 | 126 | 117.5 | 120 |
| Flight No. 394: No right-hand microphone data available. | | | | | | | |
| Flight No. 395 | | | | | | | |
| 2 | 124.5 | 126 | 125.5 | 121.5 | 120.5 | 119 | 117.5 |
| 3 | 121.5 | 120 | 121 | 116 | 112 | 107.5 | 106 |
| 4 | 125.5 | 121 | 119.5 | 118.5 | 113.5 | 110 | 107.5 |
| 5 | 128.5 | 125 | 121 | 121.5 | 118.5 | 117 | 117 |
| 6 | 120 | 117 | 117 | 111.5 | 106 | 106.5 | 108 |
| 7 | 123.5 | 120.5 | 120.5 | 113 | 108 | 108.5 | 106.5 |
| 8 | 122 | 117 | 118.5 | 114.5 | 109.5 | 107.5 | 104 |
| 9 | 123.5 | 119 | 118 | 115 | 114.5 | 115 | 111.5 |
| 10 | 123 | 122.5 | 121.5 | 118.5 | 116.5 | 112 | 111 |
| 11 | 128 | 123 | 122.5 | 119.5 | 116.5 | 114.5 | 113.5 |
| 12 | 120.5 | 118 | 118 | 115 | 108.5 | 109 | 109.5 |
| 13 | 121 | 119 | 117.5 | 115 | 112 | 111 | 109.5 |
| 14 | 119.5 | 117.5 | 118 | 114 | 109 | 108 | 109 |
| 15 | 120.5 | 120 | 120 | 115.5 | 111 | 110 | 108.5 |
| 16 | 120.5 | 120.5 | 118 | 115.5 | 110 | 108 | 108 |
| 17 | 125.5 | 121.5 | 122.5 | 119.5 | 115.5 | 111 | 110 |
| 18 | 124 | 122 | 123 | 118 | 112.5 | 109 | 106 |
| 19 | 126 | 125.5 | 127 | 121 | 118 | 113 | 114 |

TABLE VII - Continued

| Run | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| **Flight No. 398** | | | | | | | |
| 1 | 115.5 | 116.5 | 119 | 125 | 126 | 126 | 129 |
| 2 | 117 | 117.5 | 121 | 128.5 | 127 | 128 | 132 |
| 3 | 117 | 120.5 | 122 | 132.5 | 132 | 133 | 135 |
| 4 | 116.5 | 122.5 | 121 | 127.5 | 127 | 125 | 127 |
| 5 | 116.5 | 120.5 | 122 | 128.5 | 129.5 | 128.5 | 132.5 |
| 6 | 122.5 | 126 | 125.5 | 131.5 | 131.5 | 131.5 | 136 |
| 7 | 117.5 | 118.5 | 119.5 | 127 | 126.5 | 124.5 | 126 |
| 8 | 116.5 | 120.5 | 121.5 | 127 | 128.5 | 128 | 132 |
| 9 | 124 | 125.5 | 128 | 132 | 133 | 133.5 | 134 |
| **Flight No. 399** | | | | | | | |
| 1 | - | - | - | - | - | - | - |
| 2 | 130.5 | 129 | 126 | 126 | 122 | 115 | 118 |
| 3 | 127 | 125 | 121 | 119 | 116 | 118.5 | 118 |
| 4 | 129 | 127 | 128 | 124.5 | 122 | 118.5 | 118 |
| 5 | 128 | 127 | 123 | 122 | 118.5 | 115.5 | 124.5 |
| 6 | 128 | 126 | 123.5 | 123 | 132.5 | 125.5 | 116.5 |
| 7 | 126 | 126 | 123 | 125.5 | 125.5 | 121.5 | 118.5 |
| 8 | 129 | 127.5 | 127 | 123.5 | 121.5 | 121 | 119.5 |
| 9 | 128 | 125.5 | 124.5 | 125.5 | 124.5 | 121.5 | 118.5 |
| 10 | 126 | 122 | 122 | 124.5 | 124 | 122 | 120.5 |
| 11 | 126 | 123.5 | 123 | 121.5 | 121 | 122 | 114.5 |
| 12 | 126 | 123.5 | 121.5 | 121 | 115.5 | 112 | 110.5 |
| 13 | 123.5 | 122.5 | 120 | 118 | 113.5 | 109.5 | 112 |
| 14 | 125 | 122 | 121 | 120.5 | 117 | 116 | 117 |
| 15 | 130.5 | 130 | 129 | 128.5 | 124.5 | 122 | 120 |
| 16 | 123.5 | 120.5 | 122 | 118 | 110 | 109 | 107 |
| 17 | 122.5 | 122 | 121 | 119 | 114 | 112.5 | 111 |
| 18 | 121 | 123.5 | 126 | 125 | 119 | 113.5 | 110 |
| 19 | 126 | 125.5 | 123.5 | 123.5 | 119 | 112 | 108 |
| 20 | 127.5 | 127 | 121 | 121 | 120 | 116 | 116 |
| 21 | 129.5 | 125 | 123.5 | 126.5 | 120.5 | 119 | 119 |
| 22 | 118.5 | 123 | 121 | 117.5 | 113 | 109 | 109.5 |
| 23 | 127 | 124 | 121.5 | 118 | 115.5 | 115 | 116.5 |
| 24 | 125.5 | 126 | 124.5 | 121.5 | 116 | 110 | 109 |
| 25 | 134.5 | 113.5 | 132 | 129 | 126 | 123 | 116.5 |
| 26 | 129 | 123 | 119 | 120.5 | 118 | 118 | 117 |
| 27 | 125 | 121 | 119 | 119 | 114.5 | 111.5 | 111.5 |

TABLE VII - Continued

| Run | Octave Band Center Frequencies - Hz | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| | (Sound pressure level in db given below) | | | | | | |
| Flight No. 400 | | | | | | | |
| 2 | 127.5 | 128 | 125 | 124 | 121.5 | 118 | 127.5 |
| 3 | 127 | 126.5 | 127 | 124 | 123 | 120 | 127 |
| 4 | 129 | 124.5 | 123 | 122.5 | 118 | 118 | 116 |
| 5 | 123.5 | 124.5 | 123 | 120.5 | 119 | 115.5 | 115.5 |
| 6 | 127 | 128.5 | 126.5 | 125 | 122.5 | 117 | 117 |
| 7 | 124 | 123 | 123 | 125.5 | 123 | 122 | 119 |
| 8 | 127 | 123 | 120.5 | 122 | 124 | 119 | 119 |
| 9 | 126 | 123 | 122 | 122.5 | 121 | 121 | 117.5 |
| 10 | 126 | 123 | 122 | 120 | 117.5 | 117.5 | 117.5 |
| 11 | 125 | 124 | 121 | 121 | 123.5 | 118.5 | 117.5 |
| 12 | 126 | 124 | 121 | 121 | 113 | 111 | 113 |
| 13 | 124.5 | 121 | 123 | 118.5 | 113.5 | 110 | 108 |
| 14 | 127 | 123 | 119.5 | 120 | 119 | 115.5 | 116 |
| 15 | 127 | 124 | 119 | 121 | 120.5 | 119 | 120 |
| 16 | 123 | 122 | 120 | 116.5 | 113.5 | 111.5 | 113 |
| 17 | 121 | 120 | 113.5 | 116 | 112.5 | 112 | 114 |
| 18 | 124 | 123.5 | 124 | 121.5 | 118.5 | 113 | 114.5 |
| 19 | 125 | 122 | 121.5 | 119 | 114 | 112 | 114 |
| 20 | 127 | 124 | 119 | 121 | 117 | 116.5 | 117 |
| 21 | 127 | 123.5 | 120 | 121 | 118 | 119 | 117.5 |
| 22 | 120.5 | 120.5 | 119.5 | 118 | 114 | 111 | 114 |
| 23 | 122.5 | 118 | 119 | 115 | 111 | 110 | 113 |
| 24 | 123.5 | 123.5 | 123 | 121 | 116.5 | 112 | 115 |
| 25 | 120.5 | 118 | 117 | 114 | 111.5 | 111.5 | 114 |
| 26 | 125 | 124 | 123 | 119.5 | 116.5 | 115 | 116 |

TABLE VIII. AIRBORNE NOISE DATA - COCKPIT MICROPHONE

| Run | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| Flight No. 393 | | | | | | | |
| 1 | 105.5 | 107.5 | 101.5 | 105.5 | 102.5 | 107.5 | 109.5 |
| 2 | 109.5 | 108 | 102.5 | 105 | 103 | 107.5 | 109.5 |
| 3 | 114.5 | 111 | 106 | 105.5 | 102 | 106 | 108.5 |
| 4 | 110 | 108.5 | 103.5 | 105 | 103 | 108 | 111 |
| 5 | 106.5 | 109 | 105 | 105 | 102.5 | 106.5 | 109 |
| 6 | 110.5 | 108.5 | 99 | 104.5 | 102 | 106 | 108.5 |
| 7 | 108 | 107.5 | 98 | 104.5 | 102.5 | 106 | 109 |
| 8 | 108 | 108 | 99 | 104.5 | 102 | 106 | 108 |
| 9 | 114 | 109 | 100 | 103.5 | 102 | 106.5 | 108.5 |
| 10 | 114.5 | 110 | 101 | 104 | 102 | 105.5 | 107.5 |
| 11 | 113 | 110.5 | 103 | 103.5 | 102.5 | 106.5 | 108 |
| 12 | 110.5 | 108 | 99 | 103.5 | 102 | 108 | 112 |
| 13 | 114.5 | 111 | 101.5 | 104.5 | 103 | 107.5 | 111.5 |
| 14 | 108 | 108 | 101.5 | 103 | 101.5 | 106 | 115.5 |
| 15 | 110.5 | 108.5 | 102.5 | 106.5 | 103.5 | 107 | 108 |
| 16 | - | - | - | - | - | - | - |
| 17 | 110 | 108 | 103 | 107 | 103.5 | 106 | 110 |
| 18 | 107.5 | 108.5 | 101.5 | 106 | 102.5 | 106.5 | 108 |
| 19 | 107 | 107 | 99.5 | 105.5 | 102 | 105 | 108 |
| 20 | 106.5 | 107.5 | 98 | 105.5 | 102 | 106 | 109 |
| 21 | 108.5 | 106 | 97.5 | 104.5 | 103 | 106 | 108 |
| Flight No. 394 | | | | | | | |
| 1 | 112.5 | 108.5 | 102 | 104 | 100 | 104 | 106 |
| 2 | 116 | 107 | 101.5 | 103.5 | 100.5 | 105.5 | 106.5 |
| 3 | 113.5 | 108.5 | 100.5 | 103.5 | 100 | 104.5 | 107.5 |
| 4 | 117 | 109.5 | 100.5 | 103.5 | 100.5 | 106 | 106.5 |
| 5 | 115 | 111 | 106 | 104.5 | 101.5 | 107 | 107.5 |
| 6 | 116 | 111.5 | 106.5 | 105 | 106.5 | 104.5 | 106.5 |
| 7 | 112 | 106 | 98.5 | 101 | 104.5 | 104.5 | 107.5 |
| 8 | - | - | - | - | - | - | - |
| 9 | 113 | 108 | 105.5 | 100 | 102.5 | 108.5 | 106 |
| 10 | 105 | 103.5 | 97.5 | 103 | 110 | 105.5 | 108 |
| 11 | 104 | 99.5 | 97.5 | 101.5 | 105 | 102 | 107 |
| 12 | 104 | 99 | 96 | 102.5 | 105 | 101.5 | 110 |
| 13 | 105 | 99.5 | 96.5 | 102 | 105 | 101.5 | 108.5 |
| 14 | 116.5 | 111 | 103 | 103.5 | 101 | 105 | 107 |
| 15 | - | - | - | - | - | - | - |
| 16 | - | - | - | - | - | - | - |

TABLE VIII - Continued

| Run | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| Flight No. 395 | | | | | | | |
| 2 | 101 | 103 | 96 | 102.5 | 102 | 107 | 108.5 |
| 3 | 103 | 103.5 | 97 | 100.5 | 101.5 | 106.5 | 109 |
| 4 | - | - | - | - | - | - | - |
| 5 | - | - | - | - | - | - | - |
| 6 | 98.5 | 99.5 | 94.5 | 99 | 104.5 | 101 | 106.5 |
| 7 | 97.5 | 102.5 | 98 | 101.5 | 108.5 | 106 | 109.5 |
| 8 | 100 | 102 | 96 | 101 | 108 | 105.5 | 108 |
| 9 | 104 | 103.5 | 96.5 | 101 | 107.5 | 104.5 | 108.5 |
| 10 | 103.5 | 104.5 | 101.5 | 102.5 | 108 | 104.5 | 107.5 |
| 11 | 111.5 | 105 | 96.5 | 100 | 100 | 105.5 | 107 |
| 12 | 109 | 105 | 100 | 101 | 100.5 | 105.5 | 110 |
| 13 | 101 | 104.5 | 100 | 102 | 101.5 | 107 | 106.5 |
| 14 | 108.5 | 104.5 | 97.5 | 101.5 | 100 | 104.5 | 107.5 |
| 15 | 109.5 | 105 | 97 | 101 | 100 | 105 | 107 |
| 16 | 108 | 104.5 | 98.5 | 101 | 100 | 105.5 | 108 |
| 17 | 108 | 105 | 96.5 | 102 | 100 | 104.5 | 107.5 |
| 18 | 100 | 104 | 100.5 | 101 | 99.5 | 104.5 | 111 |
| 19 | 107.5 | 108.5 | 100 | 101 | 100 | 101.5 | 105 |
| Flight No. 398 | Data not available | | | | | | |
| Flight No. 399 | | | | | | | |
| 2 | 110.5 | 103.5 | 103 | 102.5 | 104.5 | 106 | 96.5 |
| 3 | 111.5 | 111.5 | 107 | 103.5 | 103 | 106 | 106 |
| 4 | 106 | 101.5 | 103 | 102 | 108 | 110.5 | 97.5 |
| 5 | 105.5 | 102.5 | 101.5 | 103.5 | 107.5 | 107.5 | 107 |
| 6 | 108 | 102 | 102.5 | 103 | 107.5 | 105.5 | 97.5 |
| 7 | 105 | 102 | 102.5 | 102 | 107 | 107 | 97.5 |
| 8 | 105 | 101 | 102 | 103 | 106.5 | 106.5 | 99 |
| 9 | 106 | 103 | 102 | 102 | 107 | 106 | 97 |
| 10 | 105 | 101.5 | 103 | 103 | 107 | 109.5 | 108.5 |
| 11 | 105.5 | 100.5 | 102 | 103.5 | 106 | 105.5 | 98.5 |
| 12 | 113 | 103.5 | 100 | 102.5 | 106.5 | 106 | 97 |
| 13 | 113.5 | 109 | 103 | 103 | 107.5 | 103.5 | 100.5 |
| 14 | - | - | - | - | - | - | - |
| 15 | - | - | - | - | - | - | - |
| 16 | - | - | - | - | - | - | - |
| 17 | - | - | - | - | - | - | - |
| 18 | 108 | 104 | 101.5 | 102.5 | 107 | 105 | 99 |
| 19 | 111 | 106 | 102.5 | 102 | 105 | 105 | 99 |
| 20 | 114 | 107.5 | 105 | 104 | 105 | 106 | 98.5 |
| 21 | 112 | 107 | 104.5 | 103 | 106.5 | 106.5 | 97.5 |
| 22 | 105 | 102 | 100 | 103 | 108 | 107.5 | 97 |

TABLE VIII - Continued

| Run | Octave Band Center Frequencies - Hz | | | | | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| | (Sound pressure level in db given below) | | | | | | |
| Flight No. 399 (Continued) | | | | | | | |
| 23 | 108.5 | 102.5 | 101 | 102 | 106.5 | 108 | 98.5 |
| 24 | 108 | 103.5 | 99 | 103 | 105.5 | 107.5 | 96.5 |
| 25 | 113 | 107 | 103 | 101.5 | 105 | 104 | 98.5 |
| 26 | 110 | 105.5 | 105 | 101.5 | 104 | 105.5 | 97.5 |
| 27 | 106.5 | 100.5 | 100 | 103 | 106.5 | 104 | 96.5 |
| Flight No. 400 | | | | | | | |
| 2 | 104 | 107 | 100 | 101.5 | 101.5 | 107.5 | 107 |
| 3 | 108.5 | 107 | 101.5 | 102 | 101 | 107 | 109 |
| 4 | 104.5 | 106 | 100 | 101 | 102 | 106 | 108.5 |
| 5 | 106 | 106 | 99 | 101.5 | 101 | 107.5 | 110 |
| 6 | 102 | 107.5 | 99 | 101 | 102 | 106.5 | 107 |
| 7 | 106 | 107 | 100 | 101.5 | 102 | 107 | 106 |
| 8 | 106 | 106 | 97.5 | 100.5 | 101.5 | 106.5 | 105 |
| 9 | 105.5 | 106 | 96.5 | 100.5 | 102 | 107 | 106 |
| 10 | 115 | 108 | 104.5 | 104 | 99 | 104 | 107 |
| 11 | 113.5 | 106.5 | 104.5 | 103.5 | 100 | 103 | 104.5 |
| 12 | 108 | 107.5 | 99.5 | 100 | 101 | 107.5 | 107 |
| 13 | 111 | 107.5 | 102 | 101 | 99 | 104.5 | 107 |
| 14 | 114 | 108 | 104.5 | 104 | 100 | 105 | 106 |
| 15 | 114 | 109.5 | 104.5 | 104.5 | 100 | 104 | 105.5 |
| 16 | 111 | 109.5 | 98 | 100 | 100.5 | 107 | 107 |
| 17 | 112 | 107.5 | 98 | 101.5 | 99.5 | 103.5 | 109 |
| 18 | 103 | 104.5 | 98 | 99.5 | 102.5 | 108.5 | 107.5 |
| 19 | 108 | 107 | 102 | 102 | 100 | 104.5 | 107.5 |
| 20 | 113 | 109 | 104.5 | 103.5 | 100.5 | 103.5 | 105.5 |
| 21 | 115 | 109 | 104.5 | 103 | 101 | 104.5 | 105 |
| 22 | 107 | 104 | 98 | 100.5 | 102 | 108.5 | 107 |
| 23 | 104 | 105 | 100 | 102.5 | 100.5 | 104.5 | 107.5 |
| 24 | 104 | 109 | 97 | 100 | 101 | 107 | 110.5 |
| 25 | 111 | 106 | 95 | 102 | 99.5 | 105.5 | 106 |
| 26 | 116 | 110.5 | 105 | 101.5 | 99.5 | 104.5 | 106 |

## APPENDIX IV

## GROUND NOISE DATA

TABLE IX. GROUND DATA - MICROPHONE AT 600 FEET NORTH SIDE (FLIGHT 399)

| Run | Azimuth re A/C (deg) | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
|---|---|---|---|---|---|---|---|---|
| 2 | 090 | 102 | 101 | 102 | 109 | 99 | 93 | 80 |
| 3 | 090 | 105 | 102 | 98 | 105 | 104 | 98 | 77 |
| 4 | 180 | 98 | 96 | 93 | 93 | 91 | 84 | 70 |
| 5 | 135 | 99 | 99 | 84 | 84 | 82 | 78 | 69 |
| 6 | 090 | 100 | 96 | 82 | 81 | 79 | 74 | 64 |
| 7 | 045 | 97 | 95 | 82 | 80 | 74 | 77 | 60 |
| 8 | 180 | 93 | 82 | 78 | 81 | 85 | 76 | 56 |
| 9 | 135 | 99 | 103 | 95 | 86 | 76 | 65 | 52 |
| 10 | 090 | 100 | 96 | 87 | 79 | 79 | 62 | 46 |
| 11 | 045 | 96 | 97 | 84 | 80 | 80 | 73 | 61 |
| 12 | 090 | 102 | 98 | 95 | 96 | 91 | 81 | 65 |
| 13 | 090 | 98 | 97 | 99 | 105 | 96 | 90 | 71 |
| 14 | 090 | 105 | 103 | 100 | 109 | 99 | 93 | 77 |
| 15 | 090 | 104 | 104 | 99 | 103 | 95 | 96 | 79 |
| 16 | 090 | 99 | 86 | 88 | 90 | 88 | 79 | 64 |
| 17 | 090 | - | - | - | - | - | - | - |
| 18 | 270 | - | - | - | - | - | - | - |
| 19 | 270 | 103 | 100 | 94 | 100 | 100 | 89 | 74 |
| 20 | 270 | 105 | 104 | 98 | 100 | 95 | 83 | 68 |
| 21 | 270 | 102 | 102 | 93 | 96 | 91 | 76 | 59 |
| 22 | 270 | 101 | 98 | 90 | 93 | 89 | 90 | 63 |
| 23 | 270 | 98 | 94 | 92 | 91 | 88 | 83 | 65 |
| 24 | 090 | 104 | 100 | 92 | 100 | 96 | 88 | 76 |
| 25 | 090 | 102 | 101 | 98 | 104 | 99 | 87 | 74 |

TABLE X. GROUND DATA - MICROPHONE AT 200 FEET NORTH SIDE (FLIGHT 399)

| Run | Azimuth re A/C (deg) | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| 2 | 090 | 112 | 114 | 116 | 115 | 107 | 100 | 90 |
| 3 | 090 | 111 | 109 | 116 | 113 | 105 | - | 91 |
| 4 | 180 | 108 | 110 | 108 | 101 | 103 | 98 | 88 |
| 5 | 135 | 110 | 111 | 106 | 101 | 101 | 95 | 86 |
| 6 | 090 | 112 | 109 | 102 | 101 | 93 | 89 | 81 |
| 7 | 045 | 108 | 108 | 106 | 99 | 98 | 93 | 87 |
| 8 | 180 | 110 | 105 | 102 | 103 | 102 | 98 | 85 |
| 9 | 135 | 113 | 118 | 121 | 109 | 104 | 98 | 85 |
| 10 | 090 | 110 | 108 | 104 | 95 | 97 | 91 | 81 |
| 11 | 045 | 108 | 109 | 104 | 98 | 97 | 89 | 82 |
| 12 | 090 | 113 | 105 | 113 | 103 | 98 | 93 | 84 |
| 13 | 090 | 113 | 108 | 115 | 110 | 102 | 97 | 89 |
| 14 | 090 | 113 | 110 | 115 | 115 | 106 | 102 | 92 |
| 15 | 090 | 109 | 106 | 112 | 112 | 103 | 95 | 82 |
| 16 | 090 | 107 | 103 | 102 | 102 | 98 | 94 | 83 |
| 17 | 090 | 106 | 103 | 106 | 106 | 102 | 93 | 85 |
| 18 | 270 | - | - | - | - | - | - | - |
| 19 | 270 | 111 | 110 | 116 | 117 | 110 | 107 | 95 |
| 20 | 270 | 113 | 107 | 114 | 111 | 103 | 98 | 86 |
| 21 | 270 | 110 | 106 | 105 | 103 | 96 | 89 | 81 |
| 22 | 270 | 110 | 104 | 103 | 106 | 101 | 91 | 85 |
| 23 | 270 | 107 | 101 | 97 | 97 | 97 | 92 | 82 |
| 24 | 090 | 115 | 113 | 108 | 110 | 103 | 97 | 88 |
| 25 | 090 | 110 | 110 | 108 | 105 | 98 | 96 | 81 |

TABLE XI. GROUND DATA - MICROPHONE AT 200 FEET SOUTH SIDE (FLIGHT 399)

| Run | Azimuth re A/C (deg) | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| 2 | 270 | 111 | 106 | 106 | 105 | 99 | 83 | 80 |
| 3 | 270 | 112 | 108 | 108 | 106 | 100 | 94 | 81 |
| 4 | 360 | 109 | 110 | 113 | 114 | 109 | 99 | 91 |
| 5 | 315 | 107 | 111 | 110 | 107 | 105 | 97 | 88 |
| 6 | 270 | 110 | 113 | 111 | 108 | 105 | 97 | 85 |
| 7 | 225 | 108 | 112 | 110 | 109 | 108 | 100 | 89 |
| 8 | 360 | 104 | 109 | 110 | 106 | 103 | 100 | 89 |
| 9 | 315 | 107 | 113 | 113 | 111 | 107 | 99 | 88 |
| 10 | 270 | 110 | 112 | 109 | 106 | 104 | 95 | 85 |
| 11 | 225 | 104 | 110 | 111 | 111 | 106 | 97 | 86 |
| 12 | 270 | 109 | 108 | 109 | 111 | 104 | 96 | 82 |
| 13 | 270 | 113 | 109 | 116 | 114 | 108 | 97 | 85 |
| 14 | 270 | 112 | 110 | 111 | 106 | 102 | 95 | 80 |
| 15 | 270 | 114 | 111 | 105 | 104 | 101 | 96 | 85 |
| 16 | 270 | 112 | 111 | 111 | 116 | 110 | 99 | 88 |
| 17 | 270 | 110 | 109 | 109 | 109 | 108 | 99 | 86 |
| 18 | 090 | 108 | 107 | 110 | 112 | 106 | 96 | 85 |
| 19 | 090 | 111 | 110 | 118 | 119 | 112 | 102 | 90 |
| 20 | 090 | 114 | 113 | 116 | 115 | 106 | 97 | 84 |
| 21 | 090 | 117 | 109 | 116 | 116 | 102 | 88 | 70 |
| 22 | 090 | 109 | 110 | 106 | 108 | 105 | 96 | 84 |
| 23 | 090 | 107 | 106 | 114 | 111 | 93 | 94 | 83 |
| 24 | 270 | 112 | 115 | 110 | 109 | 109 | 101 | 88 |
| 25 | 270 | 112 | 107 | 106 | 103 | 100 | 94 | 80 |

TABLE XII. GROUND DATA - MICROPHONE AT 600 FEET SOUTH SIDE (FLIGHT 399)

| Run | Azimuth re A/C (deg) | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
|---|---|---|---|---|---|---|---|---|
| 2 | 270 | 104 | 102 | 102 | 94 | 94 | 83 | 66 |
| 3 | 270 | 103 | 107 | 105 | 97 | 94 | 82 | 64 |
| 4 | 360 | 97 | 99 | 95 | 88 | 81 | 74 | 68 |
| 5 | 315 | 95 | 97 | 91 | 87 | 79 | 70 | 60 |
| 6 | 270 | 98 | 95 | 91 | 87 | 80 | 71 | 57 |
| 7 | 225 | 97 | 98 | 94 | 90 | 83 | 77 | 60 |
| 8 | 360 | 93 | 94 | 89 | 81 | 78 | 71 | 55 |
| 9 | 315 | 98 | 99 | 94 | 86 | 82 | 73 | 55 |
| 10 | 270 | 95 | 96 | 92 | 86 | 79 | 72 | 57 |
| 11 | 225 | 94 | 94 | 87 | 81 | 85 | 70 | 51 |
| 12 | 270 | 101 | 102 | 101 | 100 | 98 | 89 | 68 |
| 13 | 270 | 103 | 105 | 106 | 102 | 98 | - | 75 |
| 14 | 270 | 104 | 107 | 106 | 100 | 93 | 85 | 67 |
| 15 | 270 | 103 | 101 | 99 | 97 | 91 | 81 | 68 |
| 16 | 270 | 100 | 102 | 102 | 99 | 98 | 86 | 71 |
| 17 | 270 | 101 | 101 | 99 | 92 | 92 | 84 | 62 |
| 18 | 090 | 98 | 99 | 101 | 97 | 93 | 84 | 66 |
| 19 | 090 | 101 | 103 | 105 | 108 | 104 | 92 | 75 |
| 20 | 090 | 106 | 110 | 108 | 106 | 102 | 93 | 73 |
| 21 | 090 | 104 | 105 | 104 | 108 | 103 | 93 | 72 |
| 22 | 090 | 95 | 98 | 96 | 90 | 91 | 83 | 58 |
| 23 | 090 | 95 | 98 | 96 | 90 | 91 | 83 | 58 |
| 24 | 270 | 98 | 101 | 98 | 96 | 94 | 85 | 63 |
| 25 | 270 | 100 | 101 | 98 | 84 | 88 | 79 | 56 |

TABLE XIII. GROUND DATA - MICROPHONE AT 600 FEET NORTH SIDE (FLIGHT 400)

| Run | Azimuth re A/C (deg) | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| 2 | 180 | 91 | 91 | 77 | 80 | 84 | 79 | 71 |
| 3 | 135 | 97 | 97 | 82 | 82 | 88 | 78 | 74 |
| 4 | 090 | 95 | 89 | 74 | 74 | 74 | 70 | 65 |
| 5 | 045 | 98 | 97 | 84 | 79 | 83 | 78 | 70 |
| 6 | 180 | 91 | 90 | 78 | 78 | 81 | 80 | 70 |
| 7 | 135 | 100 | 103 | 89 | 81 | 75 | 80 | 73 |
| 8 | 090 | 95 | 89 | 77 | 74 | 75 | 74 | 72 |
| 9 | 045 | 92 | 98 | 81 | 79 | 84 | 79 | 71 |
| 10 | 090 | 103 | 97 | 94 | 101 | 98 | 92 | 83 |
| 11 | 090 | 101 | 100 | 97 | 105 | 98 | 93 | 88 |
| 12 | 090 | 99 | 95 | 95 | 99 | 93 | 87 | 79 |
| 13 | 090 | 97 | 93 | 96 | 101 | 94 | 91 | 81 |
| 14 | 090 | 100 | 98 | 100 | 99 | 93 | 88 | 81 |
| 15 | 090 | 100 | 102 | 100 | 103 | 100 | 96 | 84 |
| 16 | 090 | 101 | 93 | 98 | 92 | 91 | 84 | 75 |
| 17 | 090 | 95 | 93 | 91 | 87 | 86 | 85 | 79 |
| 18 | 270 | 103 | 104 | 103 | 100 | 94 | 88 | 81 |
| 19 | 270 | 103 | 106 | 109 | 104 | 110 | 94 | 87 |
| 20 | 270 | 109 | 112 | 107 | 109 | 102 | 101 | 95 |
| 21 | 270 | 111 | 112 | 105 | 101 | 95 | 89 | 88 |
| 22 | 270 | 104 | 104 | 104 | 102 | 98 | 95 | 87 |
| 23 | 270 | - | - | - | - | - | - | - |
| 24 | 090 | 102 | 99 | 86 | 89 | 90 | 84 | 77 |
| 25 | 270 | - | - | - | - | - | - | - |
| 26 | 090 | 101 | 98 | 100 | 101 | 100 | 93 | 87 |

TABLE XIV. GROUND DATA - MICROPHONE AT 200 FEET NORTH SIDE (FLIGHT 400)

| Run | Azimuth e A/C (deg) | Octave Band Center Frequencies - Hz | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| | | (Sound pressure level in db given below) | | | | | | |
| 2 | 180 | 104 | 104 | 99 | 102 | 103 | 100 | 93 |
| 3 | 135 | 111 | 108 | 103 | 98 | 100 | 97 | 92 |
| 4 | 090 | 106 | 105 | 97 | 90 | 91 | 90 | 85 |
| 5 | 045 | 110 | 110 | 100 | 97 | 99 | 95 | 89 |
| 6 | 180 | 105 | 104 | 96 | 99 | 100 | 98 | 90 |
| 7 | 135 | 112 | 114 | 106 | 103 | 101 | 96 | 91 |
| 8 | 090 | 107 | 107 | 99 | 93 | 95 | 93 | 86 |
| 9 | 045 | 105 | 108 | 98 | 96 | 98 | 94 | 87 |
| 10 | 090 | 110 | 105 | 110 | 108 | 98 | 93 | 86 |
| 11 | 090 | 112 | 107 | 111 | 106 | 101 | 99 | 88 |
| 12 | 190 | 110 | 104 | 110 | 105 | 99 | 96 | 89 |
| 13 | 090 | 106 | 103 | 111 | 108 | 101 | 91 | 88 |
| 14 | 090 | 113 | 108 | 116 | 112 | 107 | 100 | 91 |
| 15 | 090 | 112 | 109 | 108 | 108 | 105 | 98 | 88 |
| 16 | 090 | 107 | 108 | 110 | 102 | 97 | 90 | 86 |
| 17 | 090 | 103 | 102 | 95 | 95 | 93 | 90 | 86 |
| 18 | 270 | 96 | 92 | 94 | 95 | 85 | 81 | 74 |
| 19 | 270 | 95 | 96 | 94 | 91 | 89 | 82 | 74 |
| 20 | 270 | 105 | 97 | 104 | 102 | 95 | 94 | 86 |
| 21 | 270 | 106 | 102 | 97 | 97 | 88 | 85 | 77 |
| 22 | 270 | 100 | 95 | 99 | 91 | 88 | 85 | 75 |
| 23 | 270 | - | - | - | - | - | - | - |
| 24 | 090 | 116 | 111 | 103 | 109 | 105 | 98 | 90 |
| 25 | 270 | - | - | - | - | - | - | - |
| 26 | 090 | 109 | 109 | 114 | 108 | 104 | 101 | 91 |

TABLE XV. GROUND DATA - MICROPHONE AT 200 FEET SOUTH SIDE (FLIGHT 400)

| Run | Azimuth re A/C (deg) | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
| 2 | 360 | 107 | 108 | 111 | 108 | 108 | 101 | 91 |
| 3 | 315 | 107 | 111 | 109 | 105 | 106 | 100 | 91 |
| 4 | 270 | 108 | 109 | 107 | 103 | 106 | 100 | 90 |
| 5 | 225 | 106 | 112 | 110 | 107 | 108 | 101 | 91 |
| 6 | 360 | 107 | 112 | 110 | 107 | 104 | 99 | 86 |
| 7 | 315 | 107 | 110 | 108 | 106 | 106 | 102 | 92 |
| 8 | 270 | 104 | 107 | 104 | 103 | 104 | 99 | 89 |
| 9 | 225 | 106 | 112 | 109 | 108 | 108 | 102 | 93 |
| 10 | 270 | 111 | 108 | 109 | 100 | 96 | 96 | 86 |
| 11 | 270 | 111 | 109 | 108 | 107 | 99 | 95 | 88 |
| 12 | 270 | 107 | 110 | 109 | 108 | 104 | 96 | 38 |
| 13 | 270 | 107 | 107 | 114 | 110 | 103 | 99 | 87 |
| 14 | 270 | 111 | 111 | 112 | 115 | 111 | 98 | 94 |
| 15 | 270 | 111 | 111 | 107 | 104 | 101 | 96 | 87 |
| 16 | 270 | 104 | 110 | 114 | 108 | 102 | 95 | 80 |
| 17 | 270 | 103 | 100 | 99 | 100 | 98 | 93 | 85 |
| 18 | 090 | 102 | 114 | 117 | 110 | 94 | 108 | 89 |
| 19 | 090 | 107 | 111 | 114 | 108 | 104 | 98 | 88 |
| 20 | 090 | 110 | 117 | 121 | 113 | 106 | 98 | 86 |
| 21 | 090 | 113 | 115 | 112 | 111 | 105 | 96 | 86 |
| 22 | 090 | 110 | 108 | 114 | 109 | 105 | 98 | 87 |
| 23 | 090 | 104 | 113 | 113 | 106 | 103 | 107 | 83 |
| 24 | 270 | 111 | 111 | 107 | 106 | 105 | 101 | 91 |
| 25 | 90 | - | - | - | - | - | - | - |
| 26 | 270 | 109 | 112 | 111 | 105 | 99 | 93 | 86 |

TABLE XVI. GROUND DATA - MICROPHONE AT 600 FEET SOUTH SIDE (FLIGHT 400)

| Run | Azimuth re A/C (deg) | Octave Band Center Frequencies - Hz (Sound pressure level in db given below) 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 |
|---|---|---|---|---|---|---|---|---|
| 2 | 360 | 98 | 99 | 94 | 92 | 88 | 83 | 73 |
| 3 | 315 | 97 | 99 | 93 | 86 | 85 | 80 | 68 |
| 4 | 270 | 95 | 96 | 91 | 80 | 81 | 77 | 66 |
| 5 | 225 | 96 | 98 | 92 | 83 | 85 | 82 | 72 |
| 6 | 360 | 96 | 98 | 95 | 86 | 82 | 79 | 68 |
| 7 | 315 | 98 | 98 | 93 | 89 | 87 | 83 | 74 |
| 8 | 270 | 92 | 97 | 91 | 87 | 89 | 83 | 73 |
| 9 | 225 | 94 | 100 | 92 | 90 | 88 | 86 | 73 |
| 10 | 270 | 103 | 103 | 99 | 94 | 97 | 90 | 78 |
| 11 | 270 | 105 | 105 | 102 | 95 | 93 | 89 | 78 |
| 12 | 270 | 97 | 102 | 99 | 98 | 96 | 89 | 78 |
| 13 | 270 | 101 | 101 | 99 | 100 | 97 | 86 | 76 |
| 14 | 270 | 106 | 107 | 106 | 108 | 102 | 94 | 90 |
| 15 | 270 | 106 | 106 | 102 | 102 | 92 | 89 | 78 |
| 16 | 270 | 101 | 98 | 97 | 97 | 93 | 85 | 73 |
| 17 | 270 | 97 | 95 | 92 | 95 | 88 | 86 | 74 |
| 18 | 090 | 101 | 98 | 106 | 103 | 98 | 89 | 77 |
| 19 | 090 | 105 | 99 | 107 | 104 | 98 | 89 | 78 |
| 20 | 090 | 106 | 108 | 103 | 107 | 102 | 93 | 79 |
| 21 | 090 | 109 | 107 | 106 | 104 | 103 | 93 | 78 |
| 22 | 090 | 102 | 100 | 96 | 100 | 96 | 90 | 76 |
| 23 | 090 | 99 | 100 | 100 | 104 | 96 | 91 | 74 |
| 24 | 270 | 99 | 100 | 90 | 91 | 92 | 88 | 77 |
| 25 | 090 | - | - | - | - | - | - | - |
| 26 | 270 | 107 | 105 | 105 | 104 | 94 | 85 | 69 |

## APPENDIX V

## SUBJECTIVE RATING OF AIRBORNE AND GROUND DATA

TABLE XVII. SUBJECTIVE RATING OF ROTOR NOISE AIRBORNE DATA

| Run No. | True Air-speed (kn) | Rotor RPM | Long. Cyclic BITF/BITR (deg) | Subjective Rating | | |
|---|---|---|---|---|---|---|
| | | | | Microphone | | |
| | | | | Left Hand | Nose Boom | Right Hand |
| Flight No. 393. Nominal Gross Weight - 36,000 pounds | | | | | | |
| 1 | 25 | 230 | 0.5/0.0 | M | M | W |
| 2 | 25 | 230 | 0.5/0.0 | L-M | L-M | W |
| 3 | 25 | 230 | 0.5/0.0 | M | M | W |
| 4 | 25 | 230 | 0.5/0.0 | M | L-M | W |
| 5 | 25 | 230 | 0.5/0.0 | L | None | None |
| 6 | 25 | 230 | 0.5/0.0 | L | L | None |
| 7 | 25 | 230 | 0.5/0.0 | M | None | None |
| 8 | 25 | 230 | 0.5/0.0 | M | M-L | None |
| 9 | 25 | 230 | 0.5/0.0 | M | L | L |
| 10 | 25 | 230 | 0.5/0.0 | M | L | L |
| 11 | 22 | 230 | 0.5/0.0 | M | L | None |
| 12 | 56 | 230 | 0.5/0.0 | M-H | M | L |
| 13 | 61 | 243 | 0.5/0.0 | M-H | M | L |
| 14 | 52 | 243 | 0.5/0.0 | M | M-L | L |
| 15 | 55-70 | 230 | 0.5/0.0 | - | N/A | - |
| 16 | - | 230 | 0.5/0.0 | - | N/A | - |
| 17 | 0 | 230 | 0.5/0.0 | M | M | W |
| 18 | 0 | 230 | 0.5/0.0 | M | M | W |
| 19 | 0 | 230 | 0.5/0.0 | W | L-M | W |
| 20 | 0 | 230 | 0.5/0.0 | W | None | W |
| 21 | 0 | 230 | 0.5/0.0 | W | None | W |
| Flight No. 394. Nominal Gross Weight - 32,500 pounds | | | | | | |
| 0 | 0 | 230 | 0.5/0.0 | - | N/A | - |
| 1 | 51 | 230 | 0.5/0.0 | M | M-L | None |
| 2 | 90 | 230 | 0.0/0.0 | M | M-L | None |
| 3 | 75 | 230 | 0.5/0.0 | M-H | M | None |
| 4 | 88 | 230 | 2.0/2.0 | M | | None |
| 5 | 88 | 230 | 2.86/4.73 | H | M | None |
| 6 | 88 | 230 | 3.0/5.0 | H | M | None |
| 7 | 66 | 222 | 0.5/0.0 | M | L | None |
| 8 | 51 | 215 | 0.0/0.0 | - | N/A | - |
| 9 | 51 | 215 | 2.0/2.0 | H | M | None |
| 10 | 51 | 215 | 0.5/0.0 | M | L | None |

TABLE XVII - Continued

| Run No. | True Air-speed (kn) | Rotor RPM | Long. Cyclic BITF/BITR (deg) | Subjective Rating | | |
|---|---|---|---|---|---|---|
| | | | | Microphone | | |
| | | | | Left Hand | Nose Boom | Right Hand |
| Flight No. 394. Nominal Gross Weight - 32,500 pounds (Continued) | | | | | | |
| 11 | 23 | 204 | 0.5/0.0 | L-M | L | None |
| 12 | 23 | 204 | 0.0/0.0 | L-M | L-None | None |
| 13 | 23 | 204 | 2.0/2.0 | M | L-M | None |
| 14 | 72 | 235 | 0.5/0.0 | M | M | None |
| 15 | 93 | 230 | 2.9/4.7 | M-H | M-H | None |
| 16 | 55-0 | 230 | 0.5/0.0 | L-M | L-M | None |
| Flight No. 395. Nominal Gross Weight - 25,500 pounds | | | | | | |
| 2 | 0 | 230 | 0.5/0.0 | L-M | None | L |
| 3 | 51 | 230 | 0.5/0.0 | M-H | M | L |
| 4 | 88 | 230 | 2.86/4.73 | H | M | L-None |
| 5 | 123 | 230 | 3.0/5.0 | H | M | L |
| 6 | 51 | 204 | 0.5/0.0 | L-M | L-None | None |
| 7 | 51 | 215 | 0.5/0.0 | L-M | L-None | L-None |
| 8 | 65 | 215 | 0.5/0.0 | M | L-None | None |
| 9 | 92 | 215 | 2.23/3.47 | M-H | L-M | None |
| 10 | 97 | 215 | 3.0/5.0 | M-H | L-M | None |
| 11 | 69 | 230 | 0.5/0.0 | M | L-None | None |
| 12 | 69 | 230 | 0.5/0.0 | L-M | L-None | None |
| 13 | 69 | 230 | 0.5/0.0 | M | L-M | None |
| 14 | 69 | 230 | 0.5/0.0 | L-M | None | L-None |
| 15 | 69 | 230 | 0.5/0.0 | M | None | None |
| 16 | 69 | 230 | 0.5/0.0 | L-M | L | None |
| 17 | 69 | 230 | 0.5/0.0 | M-H | L-None | None |
| 18 | 69 | 230 | 0.5/0.0 | M-H | L-None | L-None |
| 19 | 69 | 230 | 0.5/0.0 | L-M | W | L |
| Flight No. 398. Nominal Gross Weight - 23,500 pounds | | | | | | |
| 1 | 122 | 225 | 3.0/5.0 | H | M | None |
| 2 | 132 | 225 | 3.0/5.0 | H | M-H | None |
| 3 | 141 | 225 | 3.0/5.0 | M-H | M-L | None |
| 4 | 122 | 235 | 3.0/5.0 | H | L-None | None |
| 5 | 132 | 235 | 3.0/5.0 | H | M | None |
| 6 | 142 | 235 | 3.0/5.0 | H | M-H | L-None |
| 7 | 118 | 230 | 3.0/5.0 | H | M-H | L-None |
| 8 | 127 | 230 | 3.0/5.0 | M-H | M | None |
| 9 | 137 | 230 | 3.0/5.0 | H | None | None |
| 10 | 143 | 230 | 3.0/5.0 | H | M | None |

TABLE XVII - Continued

| Run No. | True Air-speed (kn) | Rotor RPM | Long. Cyclic BITF/BITR (deg) | Subjective Rating | | |
|---|---|---|---|---|---|---|
| | | | | Microphone | | |
| | | | | Left Hand | Nose Boom | Right Hand |
| Flight No. 398. Nominal Gross Weight - 23,500 pounds (Continued) | | | | | | |
| 11 | 138 | 230 | 3.0/5.0 | M | L | None |
| 12 | 136 | 230 | 3.0/5.0 | M | M | None |
| 13 | 137 | 230 | 3.0/5.0 | M-H | M-H | L-None |
| Flight No. 399. Nominal Gross Weight - 27,500 pounds | | | | | | |
| 1 | 96 | 230 | 3.0/5.0 | H | M | L-None |
| 2 | 120 | 230 | 3.0/5.0 | - | N/A | - |
| 3 | 120 | 230 | 3.0/5.0 | H | M | None |
| 4 | 0 | 230 | 0.5/0.0 | M | L | |
| 5 | 0 | 230 | 0.5/0.0 | M | L | None |
| 6 | 0 | 230 | 0.5/0.0 | M | L | L-None |
| 7 | 0 | 230 | 0.5/0.0 | M | L | None |
| 8 | 0 | 230 | 3.0/5.0 | M | L | None |
| 9 | 0 | 230 | 3.0/5.0 | M | L | None |
| 10 | 0 | 230 | 3.0/5.0 | M | L | None |
| 11 | 0 | 230 | 3.0/5.0 | L-M | L-None | None |
| 12 | 40 | 230 | 3.0/5.0 | M-H | M | L |
| 13 | 80 | 230 | 3.0/5.0 | M-H | L-M | None |
| 14 | 120 | 230 | 3.0/5.0 | M-H | L-None | None |
| 15 | 130 | 230 | 3.0/5.0 | M-H | M | |
| 16 | 40 | 230 | 0.5/0.0 | L-M | L-None | None |
| 17 | 80 | 230 | 0.5/0.0 | - | N/A | - |
| 18 | 40 | 230 | 3.0/5.0 | H | M | L |
| 19 | 80 | 230 | 3.0/5.0 | H | M | L-None |
| 20 | 120 | 230 | 3.0/5.0 | H | M | L-None |
| 21 | 130 | 230 | 3.0/5.0 | H | L-M | L |
| 22 | 40 | 230 | 0.5/0.0 | M-H | L-M | L |
| 23 | 80 | 230 | 0.5/0.0 | M-H | M-H | L |
| 24 | 60 | 230 | 0.5/0.0 | M-H | M | L |
| 25 | 110 | 230 | 0.5/0.0 | M | None | L-None |
| 26 | 123 | 230 | 3.0/5.0 | M-H | M-H | L-None |
| 27 | 97 | 220 | 3.0/5.0 | M-H | None | L-None |
| 23R | 80 | 230 | 0.5/0.0 | - | N/A | - |
| Flight No. 400. Nominal Gross Weight - 27,500 pounds | | | | | | |
| 2 | 0 | 230 | 0.5/0.0 | None | L | None |
| 3 | 0 | 230 | 0.5/0.0 | None | L | L-None |
| 4 | 0 | 230 | 0.5/0.0 | L-None | L | L-None |
| 5 | 0 | 230 | 0.5/0.0 | None | L | None |

TABLE XVII - Continued

| Run No. | True Air-speed (kn) | Rotor RPM | Long. Cyclic BITF/BITR (deg) | Subjective Rating | | |
|---|---|---|---|---|---|---|
| | | | | Microphone | | |
| | | | | Left Hand | Nose Boom | Right Hand |
| Flight No. 400. Nominal Gross Weight - 27,500 pounds (Continued) | | | | | | |
| 6 | 0 | 230 | 3.0/5.0 | L-None | L | L-None |
| 7 | 0 | 230 | 3.0/5.0 | L-None | L | L-None |
| 8 | 0 | 230 | 3.0/5.0 | L-None | L | L-None |
| 9 | 0 | 230 | 3.0/5.0 | L-None | L | L-None |
| 10 | 120 | 230 | 3.0/5.0 | L-M | M | None |
| 11 | 120 | 230 | 3.0/5.0 | L-M | M | None |
| 12 | 40 | 230 | 3.0/5.0 | L-M | L-M | L-None |
| 13 | 80 | 230 | 3.0/5.0 | L-M | M | L-None |
| 14 | 120 | 230 | 3.0/5.0 | M | M | None |
| 15 | 130 | 230 | 3.0/5.0 | M | M | L-None |
| 16 | 40 | 230 | 0.5/0.0 | L-M | L | L-None |
| 17 | 80 | 230 | 0.5/0.0 | L | L-None | L-None |
| 18 | 40 | 230 | 3.0/5.0 | L-M | L-M | L-None |
| 19 | 80 | 230 | 3.0/5.0 | L-M | L-M | L-None |
| 20 | 120 | 230 | 3.0/5.0 | M | M | None |
| 21 | 130 | 230 | 3.0/5.0 | M | M | L-None |
| 22 | 40 | 230 | 0.5/0.0 | L-M | M-L-None | L-None |
| 23 | 80 | 230 | 0.5/0.0 | L-M | L-None | L-None |
| 24 | 60 | 230 | 0.5/0.0 | L | L-M | L |
| 25 | 80 | 230 | 3.0/5.0 | L-M | L-None | L-None |
| 26 | 110 | 230 | 0.5/0.0 | L-None | None | None |

L - Light Rotor Bang
M - Moderate Rotor Bang
H - Heavy Rotor Bang
W - High Wind Noise

TABLE XVIII. SUBJECTIVE RATING - STANDARD TIP AND POROUS TIP - GROUND DATA

| Run 399/400 | Azimuth (deg) | True Airspeed (kn) | Long. Cyclic BITF/BITR (deg) | Subjective Rating Microphone 200 Ft North | |
|---|---|---|---|---|---|
| | | | | Standard Tip X-399 | Porous Tip X-400 |
| 2/10 | 90 | 120 | 3.0/5.0 | M | M |
| 3/11 | 90 | 120 | 3.0/5.0 | M | M |
| 4/2 | 180 | 0 | 0.5/0.0 | M-H | L-M |
| 5/3 | 135 | 0 | 0.5/0.0 | M | M-L |
| 6/4 | 90 | 0 | 0.5/0.0 | M | L-None |
| 7/5 | 45 | 0 | 0.5/0.0 | M | L |
| 8/6 | 180 | 0 | 3.0/5.0 | M-H | L-M |
| 9/7 | 135 | 0 | 3.0/5.0 | H | M |
| 10/8 | 90 | 0 | 3.0/5.0 | M | M |
| 11/9 | 45 | 0 | 3.0/5.0 | M-H | M |
| 12/12 | 90 | 40 | 3.0/5.0 | M-H | L-M |
| 13/13 | 90 | 80 | 3.0/5.0 | H | M-H |
| 14/14 | 90 | 120 | 3.0/5.0 | M-H | H |
| 15/15 | 90 | 130 | 3.0/5.0 | M-H | H |
| 16/16 | 90 | 40 | 0.5/0.0 | M-H | M |
| 17/17 | 90 | 80 | 0.5/0.0 | M | L |
| 18/18 | 270 | 40 | 3.0/5.0 | M | L-M |
| 19/19 | 270 | 80 | 3.0/5.0 | H | M |
| 20/20 | 270 | 120 | 3.0/5.0 | M-H | H |
| 21/21 | 270 | 130 | 3.0/5.0 | L-M | M |
| 22/22 | 270 | 40 | 0.5/0.0 | M | M |
| 23/23 | 270 | 80 | 0.5/0.0 | L-None | L-None |
| 24/24 | 90 | 60 | 0.5/0.0 | M-H | M |
| 25/26 | 90 | 110 | 0.5/0.0 | M | M |

L - Light Rotor Bang
M - Moderate Rotor Bang
H - Heavy Rotor Bang
W - High Wind Noise

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13. ABSTRACT

Two sets of acoustical data were correlated. Relative blade tip-path plane positions influenced noise levels more than other operating parameters such as rotor speed or gross weight.

Porous blade tips were installed on the test aircraft. The tips reduced noise levels in hover but had no consistent effect in forward flight. However, the tips tended to decrease the sharpness of the acoustical signature at all airspeeds.

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